Guideline for Diesel Generating Plant Specification and Bid Evaluation

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ABSTRACT

This report was prepared for the World Bank by C.I. Power Services Inc. (Canada) as a guideline for use by Bank staff and consultants on power generating projects which employ large diesel engines as prime movers. It explains the characteristics and comparative advantages and disadvantages of large low speed two-stroke diesel engines and medium speed four-stroke engines intended for electric generating plant service, and develops a bid evaluation procedure to permit comparing bids for both types.

The report was originally published in July 1983 as Energy Department Paper No. 9 of the former Energy Department. It is being reprinted as a reference for the use of World Bank staff.
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SECTION 1

INTRODUCTION AND SUMMARY
1. INTRODUCTION AND SUMMARY

This guideline has been prepared to assist organizations purchasing a diesel generating plant in producing a comprehensive specification and in systematically evaluating alternatives. The suggested approach allows parallel evaluation of bids for residual fuel fired medium speed and low speed diesels. These two engine types are, in many cases, the most cost effective prime movers for base load generation in power systems with peak loads of up to approximately 100 MW. Manufacturers of both types have been working unrelentingly and with success to improve plant efficiency and to overcome some of the problems associated with burning residual fuel. A fair evaluation of the two types is possible by incorporating a cost \( \frac{1}{2} \) associated with reliability into the bid evaluation. A method of incorporating the cost of reliability is one of the main contributions of this guideline.

The cost of reliability may be included in a bid evaluation by specifying the effective capacity of the plant required rather than its site rated capacity. The effective capacity of a plant is the amount by which the load on a power system may be increased, after the plant is installed on the system, while maintaining a predetermined reliability level. It depends both on the characteristics of the plant and on the characteristics of the system to which it is added.

---

\( \frac{1}{2} \) The cost of reliability consists of three main components: reserve cost, replacement energy cost and repair cost. See for example, 'Evaluating Reliability in Purchasing Decisions' by Paul F. Albrecht - Presented at the Pacific Coast Electrical Association Engineering and Operating Conference, Los Angeles, California, March 15-16, 1979.
The concept of effective capacity is used implicitly in generation planning employing probabilistic methods (e.g. loss of load expectation method). The procedure suggested here allows a final decision on the type of diesel plant required to be deferred to the time of the bid evaluation, thus permitting the purchaser to benefit from prevailing market trends at that time. A formula and certain input data 1/ given to the potential suppliers, in the specification, allow them to select a unit or combination of units from their standard inventory that best meets the required effective capacity. The purchaser, on the other hand, is able to compare the offered plants with reasonable confidence that he may expect the same quality of service from each, although the actual site rated capacity of each may differ.

In Section 2 we review some of the circumstances leading up to the development of the types of engines available for power generation today. As we mentioned above, the two main contenders for base load generation using residual fuel oil are the four stroke medium speed trunk piston engine, and the two stroke low speed crosshead engine. These engines, especially the medium speed engine, were rapidly developed and uprated during the past two decades. During this period many users experienced problems caused by the overstressing of components due to too rapid increases in engine output. These problems were exacerbated by the use of poor quality residual fuel just before and since the fuel crisis.

1/ The most important input data are the forced outage rates of the two types of diesel plants. Ideally these should be based on statistics obtained from existing plants.
In Section 3 we show the components of a diesel generating plant and discuss the operating principles and characteristics of the medium speed engine and the low speed engine. The relative advantages for power generation of these two engine types are discussed in Section 4. The discussion includes both the undisputed physical advantages of each and the relative advantages, mainly dealing with performance, which are currently being challenged by the proponents of each type. The opinions we express are based mainly on our recent survey of residual fuel fired diesel plants. 1/

Section 5 describes some of the items essential for inclusion in a specification for a diesel plant. The purpose of the specification is to inform the bidder of the purchaser's requirements and to provide a uniform format for the responses of the bidders. In general, the specification for a 'turnkey' plant should be more comprehensive than that for a 'consultant engineered' plant to ensure that all of its components are of a high quality.

In Section 6 we show how weights may be assigned to the various advantages of each type of plant. Some features of a plant may be more, or less desirable depending upon the power system on which it is to be installed.

It is important to define performance test requirements in a plant specification. Appropriate penalties for noncompliance should also be included to discourage suppliers from overstating the expected performance of their equipment. Section 7 defines various tests for verifying the performance of the tendered plant and discusses the conditions for applying performance penalties.

1/ See Diesel Plant Performance Study prepared by C I Power Services Inc. for the World Bank, August 1980. This study is being updated for issuance as a World Bank Energy Department Paper.
Section 8 is devoted to defining the relationship between the owner, supplier and consultant. The lines of responsibility must be clearly defined for the project to be implemented successfully.

The main thrust of this guideline is to clearly define the issues relating to the purchase of a diesel plant so that all of the cost implications are properly assessed in the evaluation of bids. The total cost of producing electricity with a diesel plant is made up of:

- cost of plant
- cost of operation
- cost of maintenance
- cost of fuel
- cost of lubricating oil
- cost of reliability

Methods of quantifying most of the above items are well established but are reiterated here for completeness.

Finally in Appendix G, we evaluate a hypothetical case of two bids to further clarify the suggested procedures.
SECTION 2

BACKGROUND
2. BACKGROUND

Diesel engines are the prime movers most frequently used in the thermal generating plants of small power systems. The main reason for their extensive use is the higher efficiency of the diesel engine compared with other prime movers in the same size range such as gas turbines and small steam turbines. Another reason is the higher availability of local staff familiar with diesel engines compared to those familiar with steam turbines or gas turbines, in developing countries where most of the small power systems are located. Although in recent times diesel engines of up to 40 MW have been built, the most frequently used sizes are in the 5 to 10 MW range.

Diesel engines are usually classified by their rotational speed as high speed, medium speed or low speed. No universal standard exists for this classification. It is generally accepted that low speed refers to two stroke crosshead engines with rotational speeds of up to about 300 rpm, medium speed refers to four stroke engines with rotational speeds ranging between 300 and 700 rpm and high speed refers to two or four stroke engines with rotational speeds in excess of 700 rpm.

The fuels burned by diesel engines range from light distillates to residual fuel oils. Gas is also used, usually in conjunction with a small quantity of distillate to stabilize combustion. The distillates are refined fuels and are relatively free of contaminants. Residual fuels, byproducts of the refining of crude oil, contain the heavy fractions of the crude oil as well as metals, sulphur, and other contaminants.

After the end of World War II diesel engines began to replace the steam engines used in ships. The first replacements were large two stroke low speed engines, which were directly coupled to the propeller. These were subsequently replaced by lighter, more compact medium speed engines, although it was necessary to use a gearbox to reduce the rotational speed to match that required for the ship's propeller. The engines developed for marine use were also used for stationary electric generation applications. The fuels used at that time were almost exclusively distillates which were relatively inexpensive. The cost of equipment and cargo space and the ship's speed were of far more significance than the cost of fuel.

In the mid 1950's and into the 1960's engine manufacturers began to develop engines which could operate on heavier grades of fuel. These fuels, although heavier than the distillates previously used, were relatively free of contaminants. The main concern at that time was the control of viscosity of the fuel.

Then came the fuel crisis in 1973. Almost overnight, fuel became expensive relative to other operating costs. Higher efficiencies and the ability of engines to successfully burn the cheaper low grade fuels became of paramount importance. Initially, attempts were made to burn the cheap residual fuels using the plant that was developed for heavy but relatively clean residual fuels. The incidence of engine component failures in the medium speed engines increased and manufacturers began to change their designs to accommodate the poorer quality residual fuels. The fuel crisis had another effect. In the shipping industry, the ship's speed became secondary to efficiency. There was a trend to using slower, more efficient propellers, and to eliminate the gearbox where possible. Development work on the low speed engine was intensified.
In the late 1970's many diesel electric generating stations using residual fuel were reporting serious operational difficulties. There were frequent breakdowns and many operators found it necessary to derate the engines or to revert to the use of distillate fuel to reduce the number of failures. The engine manufacturers attributed the difficulties, especially in developing countries, to poor maintenance and operational practices. The owners attributed the difficulties to inadequate engine design to cope with the fuel being used and overrating of the engines by the manufacturers.

World Bank engineers became concerned that many of the power projects funded by the Bank in developing countries were falling short of expectations. At the same time the manufacturers of low speed diesels began to claim that their engines were inherently more suited to burning poor quality residual fuels than the medium speed engines. C I Power Services was engaged by The World Bank to evaluate the operating experience of eighteen diesel plants in sixteen countries. An effort was made to determine if there were any differences in basic design that made low speed diesels more suitable than medium speed diesels for use with residual fuels in developing countries. In particular:

- Is the low speed diesel more reliable than the medium speed diesel when burning poor quality fuel?
- Are there any features which make it more immune to abuse by partially trained staff?
- Does it require less frequent maintenance?

C I Power Services found that only five of the plants surveyed used low speed engines. Good records were available only at one, so the sample was too small to make definite conclusions about the performance of low speed diesels. However, the results obtained from the plant with relatively complete
records were very encouraging. The low speed diesels there were operating reliably, with a forced outage rate $1^/$ of only 3%. On the other hand, enough data was collected for medium speed diesels to be reasonably confident of the numbers derived. The mean forced outage rate was 23% and the best plant had a forced outage rate of 16%.

It is evident that there are many factors which should be considered when determining the appropriate type of generating plant for a given application. We must consider both the characteristics of the available engines and the characteristics of the system to which the plant will be added. Many of the factors are accounted for in the traditional approach to evaluating bids. The ones most often overlooked are the relative reliability of the engines, their relative maintenance requirements and other more nebulous factors such as resistance to abuse, spare part compatibility with existing engines, etc.

This guideline presents some of the tools that may be used to evaluate bids for medium speed and low speed engines in parallel, making allowances for their relative advantages and disadvantages. It defines the required input data. Some of the data, especially the relative life, forced outage rate, maintenance requirements and lubricating oil requirements of the two types, are still highly controversial. A more recent survey of plant performance covering the period 1980 to 1982 would supply better data than is currently available $2^/$ since more low speed diesels are now in service and there has been continuous development of the medium speed diesel for residual fuel applications.

---

$1^/$ Forced outage rate is defined as $\text{FOR} = \frac{\text{FOH}}{\text{FOH} + \text{SH}}$ where FOH is forced outage (or breakdown) hours, SH is service hours.

SECTION 3

DIESEL PLANT FEATURES
3. DIESEL PLANT FEATURES

3.1 General

Of the various subsystems that comprise a diesel plant, the engine is the most complex and accounts for about 33% of the total cost. It effectively determines the reliability of the plant since the generator is inherently very reliable and the other subsystems such as fuel treatment also are very reliable provided sufficient equipment redundancy is incorporated in their design. The subsystems comprising a plant are shown in figure 3.1, and a typical breakdown of costs is shown in table 3.2.

The two types of engines normally used with residual fuel are the medium speed four stroke trunk piston engine and the low speed two stroke crosshead engine. The physical characteristics and operating principles of each are described in the following paragraphs. Fuel quality, engine maturity and the

Figure 3.1: Typical Diesel Plant
Table 3.2: **Typical Cost Breakdown for a Diesel Plant**

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage of Total Plant Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MECHANICAL</strong></td>
<td></td>
</tr>
<tr>
<td>Engine</td>
<td>33</td>
</tr>
<tr>
<td>Lube Oil System</td>
<td>1</td>
</tr>
<tr>
<td>Cooling Water System</td>
<td>6</td>
</tr>
<tr>
<td>Control System</td>
<td>1</td>
</tr>
<tr>
<td>Fuel Oil System</td>
<td>2</td>
</tr>
<tr>
<td>Misc. Equipment</td>
<td>5</td>
</tr>
<tr>
<td>Shipment Cost</td>
<td>3</td>
</tr>
<tr>
<td>Erection &amp; Installation</td>
<td>7</td>
</tr>
<tr>
<td>TOTAL MECHANICAL CONTRACT</td>
<td>58</td>
</tr>
<tr>
<td><strong>ELECTRICAL</strong></td>
<td></td>
</tr>
<tr>
<td>Generator</td>
<td>8</td>
</tr>
<tr>
<td>Misc. Equipment</td>
<td>8</td>
</tr>
<tr>
<td>Shipment Cost</td>
<td>2</td>
</tr>
<tr>
<td>Erection &amp; Installation</td>
<td>4</td>
</tr>
<tr>
<td>TOTAL ELECTRICAL CONTRACT</td>
<td>22</td>
</tr>
<tr>
<td><strong>CIVIL</strong></td>
<td></td>
</tr>
<tr>
<td>Civil Works</td>
<td>20</td>
</tr>
<tr>
<td>including foundations</td>
<td></td>
</tr>
</tbody>
</table>
quality of staff in the plant determine the operating cost and quality of service provided by a diesel plant. The effects of properties of residual fuels on engine operation are also discussed in the following paragraphs.

3.2 Operating Principle of Diesel Engines

Both four stroke and two stroke engines operate on the air-standard Diesel Thermodynamic cycle 1/ and depend on the following physical processes:

- Air is drawn (or forced) into a cylinder and is compressed by a piston.
- Fuel is injected into the cylinder and is ignited by the heat of compression of the air.
- The burning mixture of fuel and air expands pushing the piston.
- The products of combustion are removed (scavenged) from the cylinder.
- The sequence repeats.

One of the major differences between the four stroke and the two stroke engine is the way in which air is admitted to the cylinder and the products of combustion are removed from it. Figure 3.3 shows the four stroke operating principle. As the piston moves down the cylinder, air is drawn in through an open intake valve. The piston reverses direction and, as it moves up the cylinder with both the intake and exhaust valves closed, the air is compressed. Fuel is injected, just before the piston reaches the end of its travel, and after mixing with the hot compressed air it ignites. The burning expanding mixture forces the piston back and thus does work. The final stroke of the piston forces the products of combustion out of the cylinder through the open exhaust valve. Thus there is one

1/ See, for example, Engineering Thermodynamics Work and Heat Transfer by Rogers and Mayhew - Longman.
power stroke for every four strokes of the piston.

![Diagram showing the four stroke operating principle]

**Figure 3.3:** Four Stroke Operating Principle

The two stroke engine combines some of the above steps to attain one power stroke for every two strokes of the piston (see figure 3.4). As the piston starts its upward movement, air is blown into the cylinder, through ports in the cylinder wall, to remove the products of combustion and to charge the cylinder with fresh air. As the piston moves past the ports, it compresses the air in the cylinder. Fuel is injected just before the end of the upward stroke. The mixture ignites and forces the piston back, thus doing work. The sequence then repeats.

The arrangement shown in figure 3.4 is for uniflow scavenging of the two stroke engine. This yields higher efficiencies than loop scavenging, the prime alternate method. Both depend for their operation on the use of compressed air (turbocharging) to scavenge and charge the cylinder. The effects of the scaven-
ging method and of turbocharging on engine efficiency are discussed later in this section.

Another major difference between the two types of engines being discussed is that the four stroke engine is of the trunk piston design (figure 3.5) whereas the two stroke engine is of the crosshead design (figure 3.6). This difference is significant since with the trunk piston design, products of combustion which escape past the piston rings enter the crankcase of the engine. With the crosshead design, it is possible to isolate the combustion space from the crankcase using a diaphragm (piston rod stuffing box shown in figure 3.6). The relative advantages and disadvantages of the two types are discussed in section 4.
Figure 3.5
Four Stroke Trunk Piston Engine

Figure 3.6
Two Stroke Crosshead Engine
3.3 Supercharging and Scavenging

Most modern diesel engines are supercharged. That is, combustion air is compressed before being admitted to the cylinder. The three main benefits of supercharging are:

- It increases the output power of an engine.
- It provides excess air for cooling the cylinder.
- It assists with scavenging.  

By admitting a greater mass of air to the cylinder than would occur at atmospheric pressure, it is possible to burn more fuel per cycle and thus increase the output power of the engine. By providing adequate quantities of excess air, the cylinder and exhaust passages are maintained at safe temperatures. In addition, the excess air is sometimes required to satisfy emission control standards.

The two stroke engine is more dependent on supercharging for scavenging than the four stroke engine since, unlike the four stroke engine, the piston does not sweep the exhaust out of the cylinder.

The most commonly used device 2/ for supplying compressed air to the engine is a turbocharger. It consists of a centrifugal compressor coupled to a turbine which is driven by the exhaust gas from the engine (see figure 3.7).

---

1/ Scavenging: The removal of products of combustion from the cylinder.

2/ Other devices used include reciprocating compressors, oscillating compressors, Roots blowers and axial flow rotary compressors. These are either directly driven by the engine, or by auxiliary electric motors.
Figure 3.7: Operation of Turbocharger

Two types are commonly used: constant pressure turbochargers and pulse turbochargers. The turbine of a pulse turbocharger utilizes the kinetic energy of the exhaust gas. Consequently, special exhaust manifolds are required to bring the exhaust gas from either individual cylinders or groups of cylinders into the turbine. The turbine of the constant pressure turbocharger expands the exhaust gas which is supplied to it from a large manifold that acts as an air receiver. The constant pressure turbocharger is more efficient than the pulse turbocharger, especially at the higher exhaust pressure found in modern engines. The pulse turbocharger, on the other hand, allows better engine acceleration at low loads since the turbocharger responds faster to changes in the energy of the exhaust gases.

Two stroke engines which depend entirely upon supercharging for scavenging usually require some form of auxiliary supercharger at low loads. This is usually either a separate auxiliary motor driven turbocompressor or an auxiliary compressor driven directly by the engine. In some cases a clutch is used to drive the main turbocharger at low loads. It disengages as soon as the exhaust gas has enough energy to take over the drive.
The efficiency of the engine depends, in part, upon how effectively the cylinders are scavenged. In the case of the four stroke engine, one stroke is devoted to scavenging and thus the engine can operate naturally aspirated (without turbocharging) at low loads. The two stroke engine is almost totally dependent on supercharging for its scavenging.

The two types of scavenging commonly used with the two stroke engine are loop scavenging and uniflow scavenging (see figure 3.8). Uniflow scavenging is more effective, but requires the provision of an exhaust valve. It is becoming the preferred method of scavenging as manufacturers strive to produce more efficient engines.
3.4 Design Features

Some of the parameters which describe an engine are:

- Rotational speed (rpm)
- Number of cylinders
- Output per cylinder (kW)
- Bore (mm)
- Stroke (mm)
- Brake mean effective pressure - bmep (bars)
- Peak pressure (bars)
- Exhaust gas temperature - before turbocharger (°C)
- Mean piston speed (m/sec)
- Cylinder configuration (vee or in-line)

The expression for the output power of an engine shows some of the interrelationships between the above parameters.

Output Power (kW) = \( \frac{N \times \text{bmep} \times (\text{bore})^2 \times \text{stroke} \times \text{rpm}}{C} \) (1)

Where:

- \( N \) is the number of cylinders of the engine.
- \( \text{bmep} \) is the brake mean effective pressure in bars. It is a derived quantity \( \frac{1}{2} \) and is equal to the mean indicated pressure of the cylinder multiplied by the mechanical efficiency.
- \( \text{bore} \) is the diameter of the cylinder in mm.
- \( \text{stroke} \) is the distance swept by the piston in mm.
- \( \text{rpm} \) is the rotational speed of the engine.
- \( C \) is a constant. \( \frac{1}{2} \)

---

\( \frac{1}{2} \) See Standard Practices for Low and Medium Speed Stationary Diesel and Gas Engines - Diesel Manufacturers Association, New York.

\( \frac{2}{2} \) \( C = 7.64 \times 10^8 \) for a two stroke engine and, \( C = 15.28 \times 10^8 \) for a four stroke engine.
From equation (1) we see that the output of an engine may be increased by increasing either its speed, its bmep, its bore, its stroke or the number of cylinders. The limits on these parameters are dictated mainly by the maximum allowable stress and temperature for various engine components. Table 3.9 indicates some of the factors limiting the maximum values of the above parameters:

Table 3.9: Factors Limiting Maximum Values of Engine Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Limiting Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Cylinders</td>
<td>Length of engine and consequently torsional stress in crankshaft.</td>
</tr>
<tr>
<td>bmep</td>
<td>Stress on cylinder components. Maximum attainable fuel pump pressure.</td>
</tr>
<tr>
<td>bore</td>
<td>Stress in connecting rods and crankshaft. Lubrication of bearings.</td>
</tr>
<tr>
<td>stroke</td>
<td>Height of engine.</td>
</tr>
<tr>
<td>rpm</td>
<td>Maximum piston speed that allows effective lubrication. Stress on moving components. Time for complete combustion.</td>
</tr>
</tbody>
</table>

The relationship between the rotating speed of the engine and the mean piston speed is also important.

Mean Piston Speed (m/sec) = \frac{\text{stroke} \times \text{rpm} \times 2}{60000} \quad \text{(2)}

The mean piston speed is dependant on both the rotational speed and the stroke. It is more important than the rotational speed since it determines the inertial forces on the moving components and the time allowed for combustion of the fuel.
Table 3.10 shows engine parameters published by two manufacturers, one for a four stroke medium speed engine and one for a two stroke low speed engine.

**Table 3.10: Typical Engine Parameters**

<table>
<thead>
<tr>
<th></th>
<th>4 Stroke</th>
<th>2 Stroke</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Cylinders</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Total Output</td>
<td>11 MW</td>
<td>14.4 MW</td>
</tr>
<tr>
<td>Cylinder Diameter</td>
<td>570 mm</td>
<td>670 mm</td>
</tr>
<tr>
<td>Piston Stroke</td>
<td>620 mm</td>
<td>1400 mm</td>
</tr>
<tr>
<td>Engine Speed</td>
<td>400 rpm</td>
<td>150 rpm</td>
</tr>
<tr>
<td>Mean Effective Pressure</td>
<td>20.9 bar</td>
<td>13 bar</td>
</tr>
<tr>
<td>Mean Piston Speed</td>
<td>8.3 m/sec</td>
<td>7.0 m/sec</td>
</tr>
<tr>
<td>Total Weight</td>
<td>175 tons</td>
<td>460 tons</td>
</tr>
</tbody>
</table>

3.5 Physical Dimensions of Diesel Plants

Low speed two stroke diesels are usually larger than medium speed four stroke diesels of the same rating. This can be deduced from equation (1) in section 3.4. If the bmep and number of cylinders are the same, a lower rpm must be offset by a larger bore or longer stroke to yield the same power output.

In practice, the land area required for a station with two stroke engines is slightly more than that required for a station of the same output using four stroke engines. Figure 3.11 shows a medium speed four stroke plant with a total output of 20 MW and a low speed two stroke plant with an output of 25.6 MW at the same site. The difference in area for these plants is 25%.
Figure 3.11: Layout of Low Speed and Medium Speed Diesel Plants.
Figure 3.11 also highlights the difference in land area required for two cooling methods. The two stroke low speed plant uses cooling water from wells, whereas the four stroke medium speed plant uses radiators. The cooling water pumps occupy only a small fraction of the space used by the radiators.

Either method of cooling is suitable for both engine types. In the installations shown, the low speed diesels have been more recently installed than the medium speed diesels. Well cooling at this site was shown to be feasible after the medium speed engines were installed.
3.6 Effects of Fuel Quality on Engine Operation

The viscosity 1/ of residual fuel is often taken as an indication of its suitability for use in a particular engine. Manufacturers quote their engines as being capable of burning fuel up to a certain viscosity limit. This emphasis on viscosity is misleading 2/ since viscosity is only one of the many properties of residual fuel which affect the reliability of an engine. Indeed, it is possible to have fuel with a low viscosity containing unacceptably high quantities of harmful contaminants such as vanadium and aluminium silicate. 3/

Table 3.12 summarizes the effects of some of the more important physical properties and contaminants associated with residual fuels, along with measures to mitigate their harmful effects.

Table 3.12: Properties and Contaminants of Residual Fuel

<table>
<thead>
<tr>
<th>Property/Contaminant</th>
<th>Effect</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Viscosity</td>
<td>Poor atomisation, excessive pressure in fuel pumps</td>
<td>Fuel may be heated to maintain acceptable viscosity at fuel pumps.</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>Difficulty in separating water from fuel</td>
<td>Separation is possible providing a specific gravity differential of about 1.5% exists. If the specific gravity of the fuel approaches unity, water soluble additives may be used to change the specific gravity of the associated water and thus attain the required differential.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Property/Contaminant</th>
<th>Effect</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stability</td>
<td>Poor stability results in the precipitation of sludge which may block filters</td>
<td>Stability of the fuel depends upon its blend and on temperature control. Proper blending is the responsibility of the refiner, avoiding temperature cycling is the responsibility of the user.</td>
</tr>
<tr>
<td>Cetane Number</td>
<td>If too low: poor combustion; difficult starting; rough running</td>
<td>The cetane number depends upon the blend of the fuel. Stock derived from a cracking process usually has a low cetane number.</td>
</tr>
<tr>
<td>Asphaltenes</td>
<td>Poor combustion; rapid rise in firing temperature; thermal overloading of lubricating oil film; fouling of ports and turbocharger; turbocharger fires</td>
<td>Accurate injection timing and effective atomization of fuel required to obtain complete combustion.</td>
</tr>
<tr>
<td>Carbon Residue</td>
<td>Wear; friction; fouling</td>
<td>Carbon deposits cause abrasive wear. Fuels with high Conradson Carbon residue are not acceptable.</td>
</tr>
<tr>
<td>(Conradson)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulphur</td>
<td>Corrosion of parts in combustion space and exhaust system</td>
<td>Corrosion may be minimized by the use of alkaline lubricating oils and by maintaining cylinder temperatures above the acid dew point.</td>
</tr>
<tr>
<td>Vanadium/Sodium</td>
<td>Hot corrosion, especially on exhaust valves</td>
<td>Ratio of sodium to vanadium important since sodium lowers melting point of vanadium oxides. Engine design must avoid hot spots in cylinder.</td>
</tr>
<tr>
<td>Property/Contaminant</td>
<td>Effect</td>
<td>Comments</td>
</tr>
<tr>
<td>---------------------</td>
<td>-------------------------</td>
<td>---------------------------------------------------</td>
</tr>
<tr>
<td>Solids (rust, sand, aluminum silicate)</td>
<td>Blocking of fuel pumps; liner wear.</td>
<td>Solids may be removed by using settling tanks and centrifuges.</td>
</tr>
<tr>
<td>Water</td>
<td>Injector problems, poor ignition.</td>
<td>Water may be removed by centrifuging.</td>
</tr>
</tbody>
</table>

The problems outlined above require the efforts of the oil suppliers, the users of diesel engines and the manufacturers of diesel engines to solve them. The oil suppliers are responsible for quality control of the oil. This includes ensuring that it is stored properly and not contaminated by water and other materials prior to delivery to the user. The user of the diesel engine must check the quality of oil received and provide adequate fuel treatment facilities to remove those contaminants that can be removed using current technology. The manufacturers of diesel engines must continue to develop materials and techniques to make engines more resistant to the products of combustion of low grade fuel oil.

3.7 Lubricating Oil

Lubricating oil serves three main functions in an engine. It lubricates the moving parts, assists in cooling and assists in neutralizing the acid products of combustion. The SAE grade of the oil describes its viscosity range. The TBN number describes its basicity. The TBN of the lubricating oil must be increased as the sulphur content of the fuel increases. In addition, lubricating oils usually have other additives to improve stability and to improve their detergent effect.

The selection of a lubricating oil is usually left to the engine manufacturer who bases the selection on the duty of the engine and quality of fuel used.
SECTION 4

RELATIVE ADVANTAGES OF MEDIUM AND LOW SPEED ENGINES
4. RELATIVE ADVANTAGES OF MEDIUM SPEED AND LOW SPEED ENGINES

4.1 Introduction

Both medium speed four stroke and low speed two stroke engines have unique features which give one type some advantage over the other. Some are undisputed physical advantages which are easily quantified. Others, mainly those relating to reliability and efficiency, are the subject of much debate.

To be objective, we first establish the desirable attributes of a diesel plant and then discuss the merits of each type of diesel engine in this context. The discussion relates to individual advantages of each engine type without regard for the relative importance of the advantage. In Section 6, we show how the individual features are weighted, with regard to their relative importance, when choosing the diesel plant that best meets the objective of minimizing the cost of electricity while maintaining an acceptable quality of service.

Any opinions we express in the following paragraphs are influenced by a survey of eighteen residual fuel fired diesel plants in sixteen countries 1/ and on our review of recently published papers on the subject 2/. The survey gives the user's point of view, and the published papers usually give the manufacturers' point of view.

4.2 Desirable Attributes of a Diesel Plant

The overriding objective when a diesel plant is contemplated usually is to minimize the cost of producing electricity

2/ Various Trade magazines and manufacturers' literature.
while maintaining an acceptable quality of service. To achieve this the engines used should have:

- Low Investment Cost
- Low Operating and Maintenance Cost
- High Reliability

The investment cost consists of two components: the initial price of the plant and its economic life. The initial price depends on market conditions at the time of purchase. The economic life is more difficult to judge. Although, theoretically, a plant can be made to last forever by replacing parts as they wear out, there comes a point at which it becomes obsolete because of technological advances: Spare parts become unavai-

able and have to be specially manufactured at high cost; the efficiency of the plant becomes too low relative to new designs; or the plant becomes too small for the system. As a result, a plant that is state-of-the-art and is manufactured by a company with a relatively large market share is likely to have the longest economic life.

To achieve a low operating and maintenance cost, a plant should have the following qualities:

**Fuel:**
- High fuel efficiency
- The capability of burning cheap fuel

**Lube Oil:**
- Low lubricating oil consumption (oil burned in cylinder)
- Minimum contamination of lube oil charge (thus few oil changes needed)
- Ability to use cheap lube oil (minimal additives)

**Operators:**
- Simple operation (thus few operators per engine and low level of skill for operation)

**Maintenance:**
- Low spare part cost
- Low wear rates
- Long time between overhauls
Simple assembly requirements (to minimize maintenance time)

Research on making engines more efficient continues. Most of the effort is in improving the combustion process. Heat rates as good as 8000 Btu/kWh have been obtained. Lower grades of fuel usually cost less than more refined products. It is therefore desirable for a plant to be capable of using heavy residual fuel with high levels of contaminants.

There are three concerns about the lubricating oil used in a diesel plant: cost of the oil; time between requiring a complete change due to contamination; and the quantity required to replace that which is burned in the cylinder. The cost of the oil is mainly influenced by its TBN number, which reflects the quantity of additives required for neutralizing the products of combustion. The higher the sulphur content of the fuel, the higher the TBN need be.

The number of operators and level of skill required are important considerations. If the plant, because of its simplicity, requires only relatively unskilled operators, it is more likely to be successful in a developing country.

If the diesel plant is required for base load operation, it is essential that it has a high availability. This is achieved if the need for routine maintenance is minimized, and if the plant is designed to facilitate maintenance and thus reduce its down time.

High reliability implies that the plant will start when needed and that it will not breakdown between the scheduled maintenance times.

The cost implications of high reliability are not as obvious as some of the others. If a given quality of service
is required from the total generating system, the capacity of
the plant we install to satisfy the requirement depends upon
its reliability. There are three costs associated with relia-
bility 1/: the cost of repairing a breakdown, the differential
cost of providing the energy normally supplied by the faulty
plant, and the investment cost of providing back-up plant.
One measure of reliability of a plant is its forced outage rate.2/

4.3 Undisputed Advantages of the Medium Speed Engine

The undisputed advantages of using a medium speed
trunk piston four stroke engine for power generation are:

* Price
* Weight
* Size
* Compact alternator
* Small engine components

The price of a medium speed engine is usually of the
order of 40% lower than a low speed engine with the same output
power. This is primarily because less material is required
to construct the medium speed engine. Since it is lighter than a
low speed engine of equivalent power, the medium speed engine requires
smaller, less costly foundations and is cheaper to transport.
It is also more compact than a low speed engine, especially
if built in the vee formation. Being a lighter engine and

1/ See Evaluating Reliability in Purchasing Design by Paul F.
Albrecht - A paper presented at the Pacific Coast Electrical
Association, Engineering and Operating Conference, Los Angeles,
California - March 15/16, 1979.

2/ The forced outage rate (FOR) of a plant is defined as
\[
\text{FOR} = \frac{\text{FOH}}{\text{SH} + \text{FOH}}
\]
where FOH is the forced outage hours and SH
the service hours.
having smaller components, a smaller station crane is required for construction and maintenance.

Another advantage of the medium speed engine is that of requiring a smaller alternator than a low speed engine, with a directly coupled alternator, of similar output. 1/

4.4 Undisputed Advantages of the Low Speed Engine

The undisputed advantages of using a low speed cross-head two stroke engine for power generation are:

- High output per cylinder
- Simplicity of design
- Few valves to maintain
- Long combustion time

With the two stroke engine, there is a power stroke for every revolution of the crankshaft. With the four stroke engine there is a power stroke for every two revolutions of the crankshaft. Consequently, we obtain a higher power output per cylinder from the two stroke engine than from the four stroke if all other factors are equal. 2/

The two stroke engine is usually of simple construction with large easily accessible components. This simplifies maintenance. With earlier two stroke engines there were problems with handling the large components and tensioning bolts, etc. These have been overcome by the use of special

1/ The relationship between frequency and engine speed is \( f = n_s p \) when \( f \) is the system frequency, \( n_s \) is the speed and \( p \) is the number of pole pairs. For a given frequency, a lower speed requires more poles and thus a larger alternator.

2/ See Section 3.4 Equation (1) and footnote 2.
tools and fittings, for example, hydraulic bolts. 1/

Two stroke engines usually have, at most, one inlet/exhaust valve per cylinder as opposed to the minimum two per cylinder for a four stroke engine. This reduces the valve and maintenance requirement by at least a half.

4.5 Debatable Advantages

Some of the relative advantages of medium speed and low speed engines that are currently being debated relate to:

- Availability 2/
- Reliability
- Ability to burn low grade fuel successfully
- Lubricating oil use
- "Ruggedness"
- Life of plant

We distinguish between availability and reliability deliberately. The availability of our engine is influenced both by outages caused by breakdowns and by outages caused by scheduled maintenance. Reliability relates more to unscheduled (forced) outages. An engine may be highly reliable, in that, when it is put on-line it runs until taken off, but yet it may have a low availability if it requires frequent long periods of scheduled maintenance.

1/ The bolt is fitted with a hydraulic cylinder. When it is pressurized the bolt stretches. The nut is put on and the correct tension is achieved when the hydraulic pressure is removed and the bolt shrinks.

There is an argument for low speed diesels that because of their relative simplicity, because of having few valves, and because of their higher output per cylinder, the time required for scheduled maintenance is less than that required for a medium speed engine of the same capacity. Supporters of the medium speed counter this by the argument that it is more difficult to handle the larger components of the low speed engine. In our opinion, the medium speed engine requires about a week more per year for scheduled maintenance than the low speed engine. With proper tooling and manpower scheduling both types, used for base load, can be maintained in four to five weeks per year.

The reliability of the engines is a far more contentious issue, and often so, because unlike conditions are being compared. Many factors influence reliability 1/. The most important are the engine design, the quality of fuel used, the level of skill and dedication of the operating and maintenance staff and the timely availability of spare parts. If there are high levels of vanadium and sodium in the fuel many engines suffer hot corrosion. This most often manifests itself in damage to the valves and valve seats. Low speed engine manufacturers claim that since they have no valves (loop scavenged) or only one valve (uniflow scavenged) they are less susceptible to the effects of hot corrosion 2/. Furthermore, they claim, the cylinder temperatures are lower than most medium speed engines and thus the vanadium oxides, which in the molten state cause hot corrosion, are less likely to melt. Medium speed manufacturers usually counter this by the argument that they have developed valve materials and cooling methods which minimize hot corrosion and consequent valve breakages. In our opinion, the low speed engine has a definite advantage in that it is easier to cool the cylinder components since they are

2/ See Table 3.11 in Section 3.6.
larger. Measures taken by medium speed manufacturers to improve the cooling of their valve gear often increase the complexity of the engine and require more skill for maintenance. This question can be resolved only by the collection of accurate statistics on engine performance, so that both types of engine of the same generation are compared under similar operating conditions.

Another area of contention between proponents of the medium speed engine and those of the low speed engine is lubricating oil usage. Again the argument is often at cross purposes since on the one hand medium speed manufacturers stress a low consumption of lube oil and low speed manufacturers stress their engine's infrequent need of complete oil changes. The user is interested only in spending the minimum amount to lubricate the engine effectively. The cost of lubrication depends both upon the grade of lubricating oil required and on the amount used. The grade of oil is determined by its lubricating properties (mainly viscosity) and its additives which assist in cleaning the engine and neutralizing the acid products of combustion. The TBN number of the oil is a measure of its ability to neutralize acid and generally oils with high TBN numbers are more expensive than those with low TBN numbers.

The most significant difference between the lubrication of a medium speed engine and a low speed engine is that in the medium speed engine, the combustion space is not effectively isolated from the crankcase, whereas in the low speed crosshead engine it is. Consequently, all of the oil in a medium speed engine is exposed to the products of combustion, whereas in the low speed engine only the oil injected into the cylinder is exposed. The oil in the crankcase of the low speed engine need not neutralize products of combustion and thus may be a lower grade requiring very infrequent changes. This is offset somewhat by the fact that oil of a higher TBN is required for the
cylinder lubrication of the low speed engine than is required for the lubrication of the medium speed engine. However, since the entire charge in the medium speed engine requires frequent changes due to contamination it is our opinion that the overall cost of lubricating the medium speed engine will usually be higher than the cost of lubricating the low speed engine.

The question of the relative "ruggedness" of low and medium speed engines is often debated. This is very subjective and it is our opinion that any engine subjected to excessive abuse will fail. However, there is one advantage with the low speed engine: it can continue to run with a cylinder deactivated. In the case of a failure say of an injection pump, the engine can continue to run at part load. This is not usually possible with a medium speed engine.

The relative life of medium speed and low speed engines is very difficult to assess. Much depends upon the rate of development of the engine. If many innovations are rapidly added, it tends to shorten the economic life of an engine since manufacturers rapidly move to new models and are less inclined to carry spare parts in stock for the older models. In addition to this, a user may be forced by the availability of more efficient or more reliable engines to consider early retirement of his existing plant. It is our opinion that since there is much development work in progress, decisions should not be unduly weighed by engine life since the economic life is probably shorter than the 15 to 25 years normally quoted.
SECTION 5

OUTLINE SPECIFICATION

AND CONTRACT DOCUMENTS
5. OUTLINE SPECIFICATION AND CONTRACT DOCUMENTS

5.1 Introduction

A specification for a diesel plant should achieve three main objectives. It should:

- Provide the prospective supplier with the scope of supply and technical requirements of the plant including the precise plant capacity and reliability requirements, guarantees required, test methods and penalties, the characteristics of the intended fuel, environmental conditions and the characteristics of the existing system.
- Provide the supplier with a format for presenting details of his bid.
- State the proposed bid evaluation procedure.

Two types of information are required from the supplier: performance data, and the scope of supply. The capacity and expected performance of the overall plant are required for the bid evaluation. A bill of material listing major items is required for use at the time of installation to ensure that the equipment supplied is the same as was promised in the package tendered. A bill of materials is especially important when considering plant auxiliaries, the quality and quantity of which may vary widely. It is often used as a basis for negotiating the supply of extra auxiliary equipment which may be identified as necessary after the contract has been awarded.

Information not required for the bid evaluation of implementation of the contract should not be requested. Such a request increases the cost of bidding and unnecessarily complicates the bid evaluation. In the same vein, prequalification of bidders is recommended. The cost of preparing a good tender is high and is ultimately passed on to the purchaser. It is therefore in the best interest of all concerned to reduce the list of tenderers to four or five qualified suppliers.
The specification outlined in the following paragraphs is intended for use with a 'turnkey' package. It is divided into eight parts to enable a project to be separated into smaller packages if necessary. The parts are:

5.2 Instructions to Bidders
5.3 Conditions to Contract
5.4 General Specification
5.5 Mechanical Works Specification
5.6 Electrical Works Specification
5.7 Civil Works Specification
5.8 Miscellaneous Works Specification
5.9 Price Schedule and Equipment Data

This outline deals with the preparation of a specification in a general way. A purchaser who is financing a plant through a financial institution should conform to its specific procurement guidelines 1/.

5.2 Instructions to Bidders

This part of the specification defines the general procedures for bidding, receipt and delivery of tender documents, and the conditions under which bids will be evaluated. The following items are suggested for inclusion, but these may be amended or supplemented if necessary for specific contracts.

5.2.1 General System and Project Information

In this section, an overview is given of the type of plant required, existing system and the proposed financing arrangements.

1/ See for example: Guidelines for Procurement under World Bank Loans and IDA Credits, March 1977 and subsequent revisions.
5.2.2 Scope of Work to be Contracted

A brief but concise overview of the scope of work enables the prospective bidder to make a preliminary assessment of whether or not the project is within his competence and is worth further effort in preparing a bid.

5.2.3 Invitation to Bid

Procedural items are included under this heading. These comprise the time and place of receipt of bidding documents, number of copies, language and any requirements for signing of documents.

5.2.4 Criteria for Qualification of Tenderers

This part may not be required if a prequalification was carried out. Documentation to qualify tenderers should include evidence of a well established manufacturer or contractor with good financial resources, commercial and technical know-how and proof of experience on similar projects and under similar conditions.

5.2.5 Content and Format of Tenders

The tenderer should be instructed in this section regarding the content and format of his bid presentation. It is important that this information be supplied to achieve some degree of uniformity in the tenders received and thus facilitate evaluation.
5.2.6 Project Time Schedule

The milestone dates of the project and proposed time for the award of a contract are provided under this heading. The supplier can match these dates with his existing work schedule to determine if the proposed project can be included.

5.2.7 Familiarity with Local Conditions

In most cases it is imperative that the bidder visit the project site and become familiar with local conditions. This paragraph in the specification should state the arrangements and the local contacts for such a visit.

5.2.8 Interpretation and Changes to the Specification

Procedures for clarifying points of the specification or for making amendments to the specification should be defined. The emphasis here is that any clarification of content, or changes in intent should rapidly be communicated to all of the prospective tenderers.

5.2.9 Tender Price and Format of Presentation

The instructions included under this heading define the required format for presenting the tender price. Details which are provided include the required breakdown of bid prices, the currency to be used and any applicable exchange rates. A breakdown of bid prices for major items is often required if alternative schemes are to be offered.
5.2.10 Bid Bond

The requirement for a bid bond is of questionable value. If the suppliers have prequalified, they are likely to be serious and are unlikely to make errors in bidding that would cause withdrawal of their bids. Thus the bid bond which adds to the cost of tendering is probably not justified in most cases. If a bid bond is deemed desirable, it should, to maintain confidentiality, be a fixed amount and not expressed as a percentage of the bid price. 1/

5.2.11 Validity of Tender and Bid Bond

The required period for validity of the tender, and the bid bond if specified, should be provided.

5.2.12 Performance Guarantees

There are certain performance attributes of a plant which, since they significantly affect the total cost of owning and operating the plant, are included in the bid evaluation. Suppliers should be required to guarantee these values to protect the purchaser from awarding the contract on the basis of a performance level that could not be realized. If there is a guarantee the purchaser can apply liquidated damages to, as a minimum, recover the difference in life cycle cost implied by the short fall in performance.

Items for which guarantees are usually required are:

1/ If the bid bond is expressed as a percentage of the contract price, a supplier could discover the bid price of another by obtaining information on the bid bond purchased.
- Specific fuel oil consumption of engine.
- Plant availability.
- Auxiliary plant energy consumption.
- Generator efficiency.
- Main power transformer efficiency.

This paragraph of the specification should list each item for which a guarantee is required, the test method proposed for confirming compliance and the magnitude of the penalties associated with failure to realize the promised performance.

5.2.13 Method of Tender Evaluation

The specification should state clearly the method which will be used to evaluate tenders. This method, which should reflect the requirements and objectives of the purchaser, must be presented in sufficient detail to allow each supplier to present the most suitable package from his available inventory.

The information which must be presented is:

- A list of mandatory requirements.
- A list of desirable features of the plant along with the weight assigned to each in the evaluation.
- A list of any data that may be required in determining the effective capacity of the proposed plant when it is added to the existing power system.

In addition to specific tender price adjustments to equate the auxiliary plant to that shown in the detailed specification and general adjustments for exchange rates, etc., the detailed information in the following paragraphs may be necessary.
5.2.14 Effective Capacity

The concept of effective capacity and its use in evaluating bids is shown in Section 6.2 (Value of Reliability). The information which must be included in the specification is:

- Required effective capacity expressed as a mean with upper and lower limits (e.g. $20 \pm 1$ MW).
- Maximum number of units of which plant may be comprised (e.g. 3 units).
- All units comprising plant to be of same nameplate capacity and same type.
- Equation for determining effective capacity. The equation which is used recursively is presented in Section 6.2.2 with an example of its use.
- Value of 'm' for existing system (see Section 6.2.2).
- Forced outage rates to be used for low speed two stroke and medium speed four stroke diesels.
- Whether the effective capacity calculation should be based on the site rated maximum continuous rating, or on the short time peaking rating.

5.2.15 Engine Operating Experience

This paragraph of the specification should require the supplier to provide proven engines. Ideally, to be classified as proven, the engine in its tendered model and configuration should have run successfully, for a reasonable time, on fuel with levels of contaminants comparable to the specified fuel.

This requirement often has to be relaxed to avoid excluding all engines. Adequate operating experience is a mandatory requirement, a lack of which should exclude the plant from further consideration unless substantial insured financial
guarantees are provided, including guarantees to compensate the owner for loss of production in the event of excessive failures. The definitions of successful operation, comparable levels of fuel contaminants, and reasonable operating time must be carefully determined. For base load plant in the absence of any other influencing factors reasonable figures are:

- **Successful Operation** - Service hours of at least 6000 per year, with no load restrictions due to plant problems and with a maximum of 10 unscheduled stoppages.
- **Comparable Levels of Fuel Contaminants** - Within 10% of the vanadium content, sodium content and the CCR.\(^1\) If the sodium content of the proposed fuel is considerably higher than that of the fuel presented for the experience requirement, a supplier may include fuel treatment to remove sodium.
- **Reasonable Operating Time** - two years.

These requirements may be tightened as the ability of engines to successfully burn poor quality residual fuel improves.

The experience presented by a supplier should be taken as valid only if it is independently verifiable by communication between the prospective purchaser and the user of the plant presented. To this end the supplier should be asked to list the names of users for independent verification.

5.2.16 Basic Warranty

The usual warranty offered by suppliers is for one year. The specification should state the date of effectiveness of such a warranty. It is suggested that the warranty be valid

\(^1\) This requirement may prove to be very stringent since fuel quality appears to be worsening rapidly. If it excludes all engines then the four or five that have operated on the highest levels of contaminants should be allowed.
for one year after the plant is accepted for full commercial operation by the owner. A supplier may be willing to improve on this to help offset deficiencies in the experience requirement.

5.2.17 Spare Parts

The minimum spare parts requirement must be specified. It is best to specify spares as per the requirements of a licencing authority such as American Bureau of Shipping, Norske Veritas or Lloyd's Registry of Shipping for the engine. Spares for the auxiliaries should be based on previous experience.

5.2.18 Project Experience of Supplier

This paragraph should state a requirement for the supplier to have executed at least one project of similar size and complexity in the recent past. The object of this requirement is to ensure that the supplier has demonstrated the necessary expertise in administering a complex project.

5.2.19 Financial Stability of Engine Manufacturer

Since the engine is the major component of a power plant, it is essential that we seek some indication of its maker's financial stability. If the engine manufacturer goes out of business it could shorten the economic life of the plant because of the unavailability of spare parts. Some evidence of financial viability such as a recent balance sheet should be requested. In this respect, it may be wise to deal with manufacturers who hold a reasonable share of the market.
5.2.20 Service Facilities of Supplier

The supplier should be required to demonstrate the existence of service facilities and service personnel in reasonable proximity to the proposed plant. Proximity here may be defined in terms of time of response to a request for service rather than in strict geographical terms. Language may be a consideration in this respect, since the quality of service depends upon the ability of service personnel to communicate with the plant personnel.

5.2.21 Commercial Terms

This paragraph should indicate any special requirements for commercial terms. For example a financing offer may be a mandatory requirement.

5.2.22 Engine Specific Fuel Consumption

The specific fuel oil consumption (SFOC) of the engine is of particular concern due to the high cost of fuel. The specification should include the monetary value of each gram per kilowatthour the SFOC is above or below a reference SFOC, which must be supplied. (Refer to section 6.3.2.) Since the heat rate curve of an engine is not flat, a weighting formula may be provided to determine a weighted average heat rate on which the evaluation will be based. The reference conditions for measuring the heat rate must be included here if they are not already included in the paragraph dealing with guarantees. It is particularly important to state the standard by which the calorific value of the fuel will be determined.
5.2.23 Generator Losses

The monetary value of each percentage point of efficiency above or below a specified efficiency must be given in this paragraph. The standard test procedure, if not already detailed in the paragraph on guarantees should also be included.

5.2.24 Transformer Losses

Although transformer losses consist of two parts, iron losses and copper losses, it is best for this application to treat losses in a composite way. This is done by assuming a continuous load on the transformer equal to the economic loading of the plant (most efficient load for engine). The value of each kW of losses and a reference value for losses must be stated.

5.2.25 Lubricating Oil Consumption

The frequency of lubricating oil changes is often more significant than the quantity consumed in the cylinder through combustion. Consequently the bid evaluation should be based on the total projected cost of lubricating the engine.

To facilitate evaluation, this paragraph of the specification should request the supplier to provide the following information:

- The grade of lubricating oil required for cylinder lubrication and for crankcase lubrication. 1/

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1/ In the case of the four stroke engine only one grade is usually required.
• The quantity of lubricating oil required for a complete oil change.
• The expected frequency of oil changes based on the proposed duty of the plant.
• The consumption rate of lubricating oil by combustion in the cylinders.

It is also necessary that clear procedures be set down for determining whether or not an oil change is caused by normal operation, or by accidents such as a broken water pipe, etc. The penalty for exceeding the total lubrication cost estimated for the above data should be stated if a penalty is to be imposed. 1/

5.2.26 Mechanical Design Features

To accommodate variation in reliability performance within the general types, medium speed four stroke and low speed two stroke diesel, weights are assigned for mechanical features. The features chosen are those likely to enhance the ability of an engine to operate successfully on residual fuel. The weights are applied to a small percentage of the total cost of the plant, for example to 2% of the capital cost. The amount of adjustment and the point system used is subject to the judgement of the person preparing the specification.

Typical items included as mechanical design features are detailed in section 6.7, along with a weighting

1/ It may be difficult to impose a penalty on exceeding lube oil usage since at least two years of operation may be required to show that the usage is exceeded. By that time the owner will have little leverage on the supplier.
procedure. This paragraph of the specification should state the items which will be considered, the weighting system, and the percentage of the bid price to which the weights will be applied.

5.2.27 Prime Contractor

The engine manufacturer should preferably be the Prime Contractor for a 'turnkey' package, since the engine is the major component of a diesel plant. A small adjustment of the total bid price may be made to reflect this preference. It should be no more than about 0.5%. The amount should be stated in this paragraph of the specification.

5.2.28 Supplier's Past Performance

The past performance of a supplier especially with respect to meeting contract deadlines, responding to problems and providing after sales service is an indication of his likely performance on the contract under consideration. If the consultant preparing the specification has information on file concerning the suppliers, a small adjustment of the bid price may be made to reflect these considerations.

If a supplier's evaluation is being applied, it should be so stated in the specification and the information on file regarding any supplier must be made available to that supplier on request.

5.2.29 Miscellaneous

Any other factors which are judged important to the successful completion of the contract, and which will contribute to the bid evaluation should be listed in this paragraph.
5.3 Conditions of Contract

5.3.1 General Conditions of Contract

In this paragraph we define the conditions of contract under which the successful bidder will perform the works. The use of widely accepted conditions with specific amendments for the project facilitates the understanding of the specification.

The recommended form of contract is the Conditions of Contract (International) for Civil and for Electrical and Mechanical Works published by the International Federation of Consulting Engineers (FIDIC). The FIDIC form requires completion to clearly indicate definitions, deviations and additions for the particular application. Some of the items of particular interest are:

5.3.2 Penalty for Delay in Completion

The magnitude of this penalty should be related to the loss suffered by the owner as a result of the delay. The loss is not usually easy to define since it often involves opportunity costs. In the absence of definite information, a penalty of 0.5% per week, and not exceeding 5% of the total tender price is recommended. It is usual if a penalty clause is included, to include a bonus for early completion.

5.3.3 Maintenance Period

If not specified elsewhere, a maintenance period must be specified here. Eighteen months or eight thousand operating hours is recommended. This may be superceded in many cases by a separately negotiated maintenance contract including spare parts and maintenance supervision.
5.3.4 Terms of Payment

The terms and currency of payment as well as the procedure for certifying progress payments should be defined in this paragraph. We must ensure when preparing the payment schedule, that an adequate sum is held back to cover penalties and outstanding warranty related items which become apparent at acceptance testing and during the maintenance period.

5.3.5 Price Variations

It is sometimes advantageous, for deliveries over one year, to accept a bid which is index linked to inflation rather than a firm bid into which the supplier must build price contingencies. It is most common to index link offshore costs. The formulae showing the adjustment for variations in material costs, shipping costs and labour costs, and a ceiling cost should be included in this section.

5.3.6 Customs and Import Duties and Taxes

The status of customs and import duties, and applicable taxes should be detailed in this paragraph.

5.3.7 Performance Bond

The performance bond is intended to compensate the purchaser, in the event that the supplier fails to complete the contract. It is normally of the order of 10% of the tender price.

This paragraph should include the magnitude of the performance bond, and the term of its validity. The duration
should be such that it remains in force until all claims or warranty adjustments are settled.

5.4 General Specifications

This part should provide the tenderer with the general information, and the conventions under which the contract or project is to be carried out. The following should be some of the contents:

5.4.1 Description of the Project

The quantity and range of capacity of the diesel-generator units, transformer and switchyard, fuel storage and other equipment should be described. In the description, the limit of supply of the project or contract should be defined, if possible, by means of a sketch. Procedures for interfacing with existing facilities must be clearly specified.

5.4.2 Financing of the Project

Information on the amounts, conditions of loans, names of financing institutions and details of other financing sources should be provided.

5.4.3 Existing Power Station Facilities

The information should include data on the prime movers, generators, system load, gross generation and load factor and transmission system so that the tenderer can assess the system capability and offer his most competitive diesel plant package. This information should be more detailed than the minimum provided in section 5.3.14.
5.4.4 Site and Local Conditions

In this part the location of the project the geography, topography and environmental conditions, should be described. Furthermore the accessibility by sea, air and road, the availability of services such as telephone, telex, electricity, and water and the cost thereof should be indicated.

5.4.5 Applicable Standards for Materials, Design, Manufacture and Testing

The acceptable International Standards Organizations and a selected list of applicable standards should be provided. Units of measurement, preferable the International System of Units (SI) should also be specified in this paragraph.

5.4.6 General Requirements for Design, Construction Materials and Equipment

This section should describe the general requirements for design and construction, drawings, specifications and instructions as well as for cleaning, painting, welding, galvanizing, fire prevention, piping identification and thermal insulation, lubrication, instrumentation, electrical materials, tools and interchangeability of materials and equipment.

5.4.7 Tests

Materials tests, workshop acceptance tests and performance tests should be specified. Particular care should be exercised when defining the performance tests, acceptance of
results, and application of liquidated damage charges.

5.4.8 Spare Parts

The general specification for spare parts, their manufacturing, labeling, packaging and storage should be stated. Specific spare parts for both programmed maintenance and breakdowns should be included with the equipment supply. In addition to the specified spare parts, the manufacturer should be requested to recommend his own quantity and type of spares for a given maintenance period usually 2 to 5 years. Unit prices of all spare parts should be requested.

It is important to state that the contracted spare parts are those left after commissioning and acceptance of the project. On many occasions spare parts are used during construction and are not replaced.

5.4.9 Tools and Maintenance Equipment

Although some tools and equipment should be specified, it is recommended that the manufacturer or contractor be allowed to list and quote additional tools and equipment, which he feels are necessary on site for a good maintenance program after his departure. The contractor's or manufacturer's understanding in carrying out maintenance on site can thus be assessed. Again it should be stressed that the contracted tools are those available for maintenance after commissioning and any missing tools shall be replaced.
5.4.10 Staff Training

The basic training for the supervisory and trade level personnel should be specified to include the number of personnel and the duration of their instruction in the specialized areas. Again the contractor or manufacturer should be invited to make his own recommendation.

5.4.11 Documentation

The timing and the flow of documentation such as drawings, schedules, correspondence between the owner, engineer and the contractor or manufacturers should be specified.

5.4.12 Project Drawings

The contractor or manufacturers should be provided with general project drawings including the following:

Reference Map
General Plant Layout
Powerhouse Drawings
Substation or Switchyard Layout
Generating Station Single Line Schematic
Substation or Switchyard Single Line Schematic

More detailed drawings such as for piping, wiring, etc. should be listed in the particular specification.

5.5 Mechanical Work Specification

5.5.1 General

Data, drawings and other information such as
standards for the mechanical works should be described or listed.

Any data provided should allow the tenderer to quote on either a two or four stroke diesel engine with its specific accessories and auxiliaries. The specification should state the capacity range and minimum and maximum number of units allowed.

The drawings provided to the tenderer should show intended orientation, elevation and location of engine components and auxiliaries making allowance for minor changes by the tenderer.

5.5.2 Scope of Work

A scope of work should outline the work to be considered mechanical in the context of the tender.

5.5.3 Fuel Data

Fuel specifications should be provided for Bunker 'C' and distillate fuel giving all test methods. The fuel specification should also indicate the quality of fuel believed to be available in 10 to 20 years' time with an indication of limits in vanadium, sodium, CCR, specific gravity, cetane number and other characteristics of the fuel.

5.5.4 Heat Rate

Guaranteed heat rates at various load points (e.g. 50%, 75%, 100% and 110% of MCR) may be requested. The formula showing the weighting for the purpose of evaluating the
tender should be provided. Otherwise, if a single heat rate is used for the guaranteed performance, the load level at which it should be taken must be specified.

5.5.5 Cooling Water

A cooling water chemical analysis should be included giving details of both primary and secondary cooling water available at the site.

For cooling systems with radiators, the maximum expected solar flux should be indicated to the tenderer for the sizing of the radiators and systems.

5.5.6 Equipment Supply and Erection

Under this heading the requirement for the prime movers and the associated equipment should be described.

The following equipment and material should form part of the mechanical supply:

- Diesel engine with foundation frames and anchor bolts, attached components such as combustion air systems, exhaust gas system with waste heat boilers, pumps, piping, valves, turning gear, governor, control equipment and instrumentation, wiring, control panels, motor control centres and cabling, gratings, stairs and operating platforms. Consideration should be given, when specifying, to the potential use of waste heat other than for fuel heating.

- Heavy and light fuel oil systems with treatment plant including water washing, centrifuges and homogenizers as required, tanks, purps, heaters, piping and steam tracing,
valves, control equipment and instrumentation, motors, motor control centres and cabling.

- Lube oil systems with tanks, pumps, preheaters, piping, valves, filters, motors, piping, centrifuges and treatment plant, controls and instrumentation, motor control centre and cabling.

- Jacket, valve and other primary or secondary cooling water systems, complete with tanks, pumps, heat exchangers, piping, valves, make-up and water treatment system, strainers, oil separators, control equipment and instrumentation, motor control centres and cabling.

- Starting air systems, with air receivers, piping, valves, air compressors, motor control centres and cabling. The number of starts and the rate of filling of the tanks should be specified. For instrumentation air the quality should be specified.

- Heating system, with auxiliary boiler for startup and for sludge disposal, condenser with tank, surge tank, piping, pumps, motors, chemical treatment plant, control equipment and instrumentation, motor control centres and cabling.

- Central control equipment with annunciators, instruments, alarm devices including wiring.

- Specific spare parts, tools and chemicals. The equipment specification should be functional as much as possible, leaving the tenderer to select the equipment. However, capacities of the equipment, number of units, redundancy of equipment, the changeover capability without service interruption of strainers, filters, heat exchangers, etc. must be specified. Also it may be desirable to specify the heat exchanger tubing based on local experience. Noise limitations of various locations should be defined.

- Packing, sea, air and land transportation and transportation insurance for the mechanical works.

- Cost of erection, commissioning, site and performance tests and erection insurance.
5.5.7 Factory Tests

Workshop and material tests, certificates, and the witnessing of tests should be specified to allow proper assessment of equipment performance and of materials at an early stage. Fuel oil consumption tests are of particular importance.

5.5.8 Commissioning Procedure

The commissioning procedure should be defined to include the duration and witnessing of operational tests as well as responsibility of the contractor, engineer and owner during the commissioning up to commercial operation of the plant.

5.5.9 Site Tests

These tests should include checks for proper erection such as for completeness, alignments, functional alarm control and protection tests, load rejection tests. The most important test however, is the performance test. The duration of loads, measuring techniques for fuel and lubricating oil, tolerances, points of "input" and "output" must be clearly defined to calculate deviations from the guaranteed figures (see section 7). The accuracy of the measuring instruments should be specified by the Engineer and be included as part of the scope of supply of the contractor.

5.6 Electrical Work Specification

5.6.1 General

Drawings, schematics and other information and data including specific electrical standards and norms should be provided.
The drawings should show cable routings for interconnection with existing facilities, the location of switchgear, structures and transformers. The schematics should provide the tenderer with adequate data to enable him to supply equipment compatible with the existing system.

5.6.2 Scope of Work

The scope should outline the electrical works considered for the tender.

5.6.3 Equipment Supply and Erection

A complete description of all electrical equipment should be provided. Special emphasis should be paid to details to assure compatibility with existing system components. Some of these items include protective relaying equipment, insulation levels, system stability considerations, flywheel effect, system short circuit capability, excitation response and voltages.

Below is an abbreviated list of items considered for an electrical supply. Some items however, may form part of another contract or may not be required for the particular project:

- Generator complete with coolers, bearings, foundation frame and bolts, terminal equipment, static or rotating excitation system, and special tools. The guaranteed efficiency of the generator and exciter at 50%, 75%, 100% rated capacity should be requested.
- Step-up power transformer complete with bus or cable duct connecting to the generator terminal equipment. The sizing of the power transformer should be specified such that at normal operation of the plant, no fan cooling is required.
• High and low voltage switchgear as required for the generator terminal equipment, step-up transformer, station service transformer and black start facility.

• Station service transformer or transformers to operate all plant auxiliaries with a high degree of reliability. The transformer should be sized to produce the least losses at normal operation.

• Complete self-contained diesel/electric generator for black start of the diesel plant and other emergency duty. Although this diesel/electric generator may only be required on rare occasions it is normal practice to start and operate the unit on a weekly basis. The fuel consumption should therefore be reasonable.

• Complete control system with boards, relay panels, dc batteries, chargers and panels. A complete description of the minimum required relays should be provided.

• Complete HV switching station to terminate the step-up power transformer complete with circuit breakers, disconnects, potential and current transformers and protection.

• All high and low voltage power cables between equipment of this tender and others as specified and grounding.

• Specific spare parts.

• Packing, sea, air and land transportation and transportation insurance for the electrical equipment.

• Erection, commissioning, site and performance tests and erection insurance.

### 5.6.4 Factory Tests

Workshop, material tests, certificates and the witnessing of tests should be specified to allow assessment of equipment performance at an early stage.
5.6.5 Commissioning Procedure

This should be similar to 5.5.8.

5.6.6 Site Tests

The tests should indicate verification of proper erection, insulating tests, verification of motor data, HV, dc test of the stator winding and transformer, characteristics of generator and exciter, temperature rise tests, parallel operation, load rejection and functional tests of all protective devices, control and alarm functions.

The performance tests should be made to verify guaranteed values and the specification shall describe the required instrumentation and accuracy of the devices to determine generator efficiency, step-up transformer and station service transformers, losses and the power requirement to operate the units. The required instruments should be supplied as part of the contract.

5.7 Civil Works Specification

5.7.1 General

Under this heading all general information pertaining to the civil contract and not already provided in other sections should be described. This includes applicable standards and particular testing norms.

5.7.2 Scope of Work

The scope of work should define the civil works of the tender.
5.7.3 Building Design

The tenderer should be provided with drawings and details showing special arrangements for offices, washrooms, lockers and shower rooms, control room, storage room, water test laboratory, maintenance areas, workshops and pumphouses.

Building design limits for high wind and flood conditions should be provided.

The buildings should preferably be designed for self-ventilation, but pressurized or forced air ventilation may be required under certain conditions.

5.7.4 Soil Conditions

A soil profile consisting of sub soil characteristics as well as special conditions like ground water should be provided.

Although the Engineer may interpret the results of the soil tests and subsequently recommend a certain foundation type it is preferred to leave this task to the contractor.

5.7.5 Cleaning, Excavations, Backfilling

Only normal general requirements need be specified.

5.7.6 Formwork, Reinforcing and Concrete

The requirements for formworks, coating, reinforcing steel, concrete materials, proportioning, mixing,
pouring, testing and curing of concrete should be specified. Special procedures for hot weather concreting should be detailed as required.

5.7.7 Engine Foundation

The engine foundations should be specified in such a way as to assure that the engine manufacturer will warrant the foundations along with his engines and will provide adequate supervision during the construction of the engine foundations.

5.7.8 Structural Steel, Siding, Roofing

Only sufficient details need be provided to assure good end results.

5.7.9 Others

The appropriate standards and functional requirements should be specified for items such as floors, masonry, painting, floor grates, ceilings, glazing, doors, frames, hardware, etc.

5.7.10 Overhead Cranes

Only the functional requirement need be specified. An auxiliary hoist for the main engine room crane should be included. The capacity for the main hoist would depend on the maximum component to be lifted and the selection should therefore be left to the tenderer.
5.7.11 Grading and Landscaping

The extent of responsibility of the tenderer with regard to the grading and landscaping should be specified.

5.7.12 Fuel Storage

The capacity of the required fuel storage tanks should be specified by the Engineer. This should take into account shipment intervals and adequate reserves in case of an emergency. Also safety features such as containment dykes and other protection should be specified in compliance with applicable codes.

5.7.13 Temporary Offices and Facilities

Any requirement for Engineer's offices or for the tenderer's personnel should be indicated.

5.7.14 Material Quantities

Estimated quantities of materials, specific data for equipment and supplies as well as specified suppliers should be included in the data sheets as described in 5.9.

5.8 Miscellaneous Work Specification

5.8.1 General

The following miscellaneous equipment and works could form part of the main contract or separate supplies including local contracts. For any such separate contract adequate data
schedules, drawings and specifications will have to be supplied to assure good timing and proper erection and supply.

5.8.2 Fire Fighting Equipment

Location, capacity and type of portable fire extinguishing equipment must be specified.

For stationary equipment, the capacity of the water tank, pump and type of drive as well as the routing and sizing of the ring main, location of standpipes, hoses and type of spray nozzles should be specified.

Where CO₂ or dry chemical equipment is required, the capacity, control and location of the tanks and spray nozzles should be specified.

5.8.3 Lighting System

The type of lighting and intensities should be specified in the various work areas. Any high pressure discharge lighting should be supplemented by fluorescent or dc lighting to provide minimum lighting levels following voltage dips or power outages. The limit of supply should be clearly defined.

5.8.4 Heating, Ventilation, Air Conditioning

The location of the equipment, capacity amount of units, and the environmental parameters should be defined for the various work areas.
5.8.5 Miscellaneous Equipment and Furniture

The equipment and furniture required for an efficient operation of the plant should be specified. These include furniture for offices and control room, mechanical and electrical workshop furniture, machines, tools and other equipment, and chemical laboratory equipment and furniture.

5.9 Price Schedule and Bid Form

5.9.1 General

The purpose of the price schedule is to facilitate the evaluation and comparison of the tenders. The format of the price schedule must be provided to the tenderers and include units of measurements (preferable SI) and the estimated or preferred quantity of materials or equipment. The components should be broken down into major equipment in order to make adjustments and in order to serve as a basis for civil works price adjustments in the construction phase and to indicate spare part costs for future purchases.

The price schedule should also show the local and foreign components of materials, supplies and equipment as well as local and foreign labour costs for the erection, commissioning, testing and subsequent maintenance of the equipment.

The equipment data sheets on the other hand should provide values, dimensions, weights and other information to allow an assessment of the quality and suitability of the equipment being supplied. The content of the data sheets will also serve as a check list to verify the installation of the offered materials and equipment.
Other information to be supplied with the tender includes a list of drawings, instruction manuals, a time schedule showing the equipment supply and an estimate of the manpower requirements for the installation. Provision should also be made for the names and functions of possible subcontractors to be listed.

In the case of projects where cost escalation is allowed, cost index data sheets for the different components and the source for indexing should be provided to the tenderers.

We list below a selection of specific breakdowns by contract or discipline for costing purposes. This however, may be arranged depending on subsequent contractual arrangements. Typical data requirements for equipment and supplies are also provided below. The suggested data and breakdown is not intended to be complete, but provides a guide for preparing the specification.

5.9.2 Civil Works

The breakdown of costs for the civil works should be divided into local and foreign costs by unit of measurement and for the estimated volume and quantity. By providing the unit costs, any unforeseen quantity adjustments during construction are facilitated.

Major components for civil works of a diesel power plant project are:

| Engineering | Windows |
| Mobilization | Doors |
| Clearing | Ceilings |
| Steel Structure | Ventilators and Louvers |
| Piling | Tiling |
Excavation  Flooring
Backfilling  Asphalt
Formwork  Painting
Concrete  Supplies
Masonry  Transportation
Roofing  Insurance
Siding  Erection
Drainage  Temporary Buildings

The information to be supplied in the data sheets should include building ventilation data for example and depending on the supply information such as speed, power, capacity, and overload factors for cranes.

5.9.3 Mechanical Works

As for the civil works the identifiable mechanical works should be divided into local and foreign cost components. The desired quantity of identical equipment should be listed in such a way as to allow a meaningful comparison between the two types of diesel engines. The price schedule should also allow tenderers to quote additional equipment for improved reliability.

Major headings for the mechanical works are as follows:

- Diesel engine and attachments.
- Compressed air starting system.
- Combustion air system.
- Exhaust gas system.
- Hot water or steam (waste heat) system.
- Lubricating system.
- Cooling water systems.
- Fuel oil system.
- Fuel oil storage system.
Other mechanical equipment.
Controls, cable and wiring.
Routine and strategic spare parts.
Tools and maintenance equipment.
Shipment and insurance.
Erection.
Commissioning.
Testing.
Training.
Maintenance contract.

A performance schedule providing the basis for guarantee and possible liquidated damage claims should be provided with the other equipment data sheets. The data sheets should cover all mechanical works equipment such as:

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumps</td>
<td>Strainers</td>
</tr>
<tr>
<td>Valves</td>
<td>Filters</td>
</tr>
<tr>
<td>Tanks</td>
<td>Control valves</td>
</tr>
<tr>
<td>Heat Exchangers</td>
<td>Controls</td>
</tr>
<tr>
<td>Compressors</td>
<td>Pipework</td>
</tr>
<tr>
<td>Centrifuges</td>
<td>Insulation</td>
</tr>
<tr>
<td>Motors and Controls</td>
<td></td>
</tr>
</tbody>
</table>

Some of the information to be supplied by the tenderer on the above equipment is as follows:

<table>
<thead>
<tr>
<th>Information</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maker's name</td>
<td>Arrangement</td>
</tr>
<tr>
<td>Quantity</td>
<td>Capacity</td>
</tr>
<tr>
<td>Type</td>
<td>Dimensions</td>
</tr>
<tr>
<td>Size</td>
<td>Weights</td>
</tr>
<tr>
<td>Materials</td>
<td>Plate thickness</td>
</tr>
<tr>
<td>Working pressure</td>
<td>Motor nameplate data</td>
</tr>
<tr>
<td>Capacity</td>
<td>Efficiency</td>
</tr>
<tr>
<td>Power requirement</td>
<td>Motor insulation</td>
</tr>
<tr>
<td>Flow rates</td>
<td>Starting and stalling torque of motors</td>
</tr>
</tbody>
</table>
5.9.4 Electrical Works

The electrical equipment supply should also be divided into local and foreign cost components and quantities should be indicated where possible.

Major electrical equipment for a power station includes:

- Generator and exciter.
- Controls and protection.
- Outdoor substation.
- HV Switchgear.
- Main power transformer.
- Station supply transformer.
- Auxiliary transformers.
- HV and LV cabling.
- Battery and charger.
- Motor control panels.
- Switchboards and panels.
- Other electrical equipment.
- Routine and strategic spare parts.
- Shipping and insurance.
- Erection.
- Commissioning.
- Testing.
- Training.

A performance schedule for the major equipment such as generators, exciter, power transformers and emergency generator set should form part of the data section to be completed by the tenderer. This schedule would form the basis for
guarantees and possible liquidated damage claims. The items of information to be provided by the tenderer for the supply of the electrical equipment is too numerous to be listed and only a selection of the more important data is listed below. These can be divided into three main categories namely basic nameplate data, performance data and design data as well as informative data to check adaptability of the equipment to the existing system.

<table>
<thead>
<tr>
<th>Manufacturer's Name</th>
<th>Voltage Taps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed Limits</td>
<td>Harmonics</td>
</tr>
<tr>
<td>Flywheel Effect</td>
<td>Short Circuit Withstand</td>
</tr>
<tr>
<td>Capacities</td>
<td>Short Circuit Rating</td>
</tr>
<tr>
<td>Voltages</td>
<td>Impulse Voltage Withstand</td>
</tr>
<tr>
<td>Currents</td>
<td>Accuracy Class</td>
</tr>
<tr>
<td>Power Factors</td>
<td>Ratios</td>
</tr>
<tr>
<td>Insulation</td>
<td>Materials</td>
</tr>
<tr>
<td>Efficiencies</td>
<td>Dimensions</td>
</tr>
<tr>
<td>Weight</td>
<td></td>
</tr>
<tr>
<td>Resistances</td>
<td></td>
</tr>
<tr>
<td>Reactances</td>
<td></td>
</tr>
<tr>
<td>Impedances</td>
<td></td>
</tr>
<tr>
<td>Time Constants</td>
<td></td>
</tr>
<tr>
<td>No Load and Load Losses</td>
<td></td>
</tr>
<tr>
<td>Type of Cooling</td>
<td></td>
</tr>
<tr>
<td>Temperature Ratings</td>
<td></td>
</tr>
</tbody>
</table>

5.9.5 Miscellaneous Works

As mentioned in 5.8.1, the miscellaneous works could form part of the main contracts and/or be tendered separately through local contractors. In any case, the cost schedules should be issued for completion to make a comparison easy. Items falling under the miscellaneous category are:
Indoor and outdoor lighting.
Fire fighting systems.
Heating.
Ventilation.
Furniture and appliances.
Office equipment.
Erection.
Transportation.
Insurance.

The data sheets for the above items should request information from the tenderer such as:

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Power Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Power Requirement</td>
</tr>
<tr>
<td>Ratings</td>
<td>Control</td>
</tr>
<tr>
<td>Capacity</td>
<td>Materials</td>
</tr>
<tr>
<td>Pressures</td>
<td>Weights</td>
</tr>
<tr>
<td>Voltage</td>
<td>Dimensions</td>
</tr>
<tr>
<td>Power Factor</td>
<td></td>
</tr>
</tbody>
</table>
SECTION 6

BID EVALUATION
6. BID EVALUATION

6.1 Introduction

The parallel evaluation of bids for medium speed four stroke and low speed two stroke diesel generating plant is usually preceded by the following circumstances:

- The prospective purchaser needs additional generating capacity to meet increasing loads and to maintain or improve the quality of service.
- Preliminary planning has shown diesel generating units burning residual fuel to be the least cost of the various generating technologies suitable for the application.
- A number of suppliers have been invited to compete for the contract to supply the required generating unit or units.

The objective of the evaluating process is to select the bid which provides the necessary generating plant capacity with the required quality of service at the lowest cost. To achieve this objective we proceed with the following steps:

- We check whether or not the alternatives being considered offer essentially the same quality of service to the purchaser (are we comparing apples with apples?).
- The prices of alternatives are adjusted, where necessary, to account for any additional equipment that may be necessary to attain the required quality of service.
- For each alternative we calculate the cost of producing the required energy for the expected lifetime of the plant.
- If the life expectancy of the engines used in the various alternatives is different, we adjust the price to reflect this.

The above evaluation steps may be broken into a series of small logical decisions. The process is further simplified if we recognize that there are certain essential requirements, 'musts',
and certain desirable items, 'wants', associated with the evaluation. Failure to satisfy a 'must' results in disqualification of the bid. The 'wants' are assigned weights proportioned to their importance to the purchaser.

We must consider the time value of money when determining the total cost of owning, operating and maintaining each plant through its expected lifetime. Some costs are incurred at the time of purchase and others accrue annually throughout the life of the plant. The present value of each future cost is calculated prior to adding it to the initial cost.

One way to calculate this life cycle cost is first to determine the expenditure in constant dollars for each year of the life of the plant, and then to calculate the cumulative present value of the resulting cost stream. A related technique is to take a 'snapshot' of one year's cost by using levelized values to cater for the present value of future costs. The results in both cases may be expressed as total cost for the life of the plant. (See Appendix C for an example of the two approaches applied to a hypothetical case.)

Table 6-1 is a typical summary for a bid evaluation. The mandatory items are listed first. This table is not exhaustive and indeed should be modified to reflect the unique requirements of a purchaser. Some of the most frequently encountered issues are listed.

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1/ See the Rational Manager by Charles H. Kepner and Benjamin B. Tregoe - McGraw-Hill Book Company.

2/ For economic comparison, inflation must be ignored. Escalation of costs should be shown if the cost of the item in question increases at a rate different from the average rate of inflation.
### Table 6.1: Typical Evaluation Summary Sheet

<table>
<thead>
<tr>
<th>EVALUATING ITEM</th>
<th>BIDS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td><strong>NUMBER</strong></td>
<td></td>
</tr>
<tr>
<td><strong>DESCRIPTION</strong></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Engine operating experience.</td>
</tr>
<tr>
<td>2</td>
<td>Effective capacity requirement.</td>
</tr>
<tr>
<td>3</td>
<td>Basic warranty.</td>
</tr>
<tr>
<td>4</td>
<td>Minimum spare parts requirement.</td>
</tr>
<tr>
<td>5</td>
<td>Experience by supplier on similar projects.</td>
</tr>
<tr>
<td>6</td>
<td>Financial stability of engine manufacturer</td>
</tr>
<tr>
<td>7</td>
<td>Service facilities of supplier.</td>
</tr>
<tr>
<td>8</td>
<td>Commercial terms.</td>
</tr>
<tr>
<td>9</td>
<td>Tendered price of plant.</td>
</tr>
<tr>
<td>10</td>
<td>Equipment equalization.</td>
</tr>
<tr>
<td>11</td>
<td>Base price (adjusted for equipment equalization).</td>
</tr>
<tr>
<td>12</td>
<td>Price after adjustment for life expectancy.</td>
</tr>
<tr>
<td>13</td>
<td>Specific fuel consumption.</td>
</tr>
<tr>
<td>14</td>
<td>Generator losses.</td>
</tr>
<tr>
<td>15</td>
<td>Main power transformer losses.</td>
</tr>
<tr>
<td>16</td>
<td>Auxiliary power consumption.</td>
</tr>
<tr>
<td>17</td>
<td>Lubricating oil consumption.</td>
</tr>
<tr>
<td>18</td>
<td>Maintenance cost.</td>
</tr>
<tr>
<td>19</td>
<td>Mechanical design features.</td>
</tr>
<tr>
<td>20</td>
<td>Engines similar to existing engines in plant.</td>
</tr>
<tr>
<td>21</td>
<td>Arrangements for training of staff.</td>
</tr>
<tr>
<td>22</td>
<td>Engine manufacturer as prime contractor.</td>
</tr>
<tr>
<td>23</td>
<td>Supplier's past performance.</td>
</tr>
<tr>
<td>24</td>
<td>Miscellaneous.</td>
</tr>
</tbody>
</table>

**TOTAL EVALUATED COST**
We will emphasize a technique for quantitatively estimating the quality of service expected from the plant offered by a supplier. This aspect of the evaluation was often ignored in the past since the engines being compared exhibited very similar reliability characteristics. With the increasing use of poor quality residual fuel, it has become evident that some engines can burn this fuel more successfully than others. Consequently to ignore an estimation of reliability in the evaluation process is likely to lead to incorrect purchasing decisions.

The discussion so far has been directed to the economic evaluations of bids. If financing offers are sought and are pertinent to the purchase decision, the cost of financing as implied by each offer should be determined separately and added to the costs obtained from the economic evaluation.

The remainder of section 6 is devoted to suggesting methods of expressing the worth of the items listed in table 6-1.

6.2 Value of Reliability

6.2.1 General

The reliability of a diesel plant has a significant effect on the cost of producing electricity. Three costs, related to reliability, which should be considered are: repair cost, reserve cost, and replacement energy cost.\(^1\)

\(^1\) The repair cost associated with an unscheduled stop (breakdown) may be estimated by assessing the likely extent of damage and the cost of spare parts and labour for the resulting

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repair. This is a subjective assessment unless it is based on a well documented operating history of the engine in question. Of greater importance are the reserve cost and replacement energy cost.

Every generating unit included in a power system needs to have some portion of its capacity covered by a backup unit to cater for the time when it is being maintained or is defective. The percentage of its capacity required in reserve is a function of the time that it is unavailable for use. The cost of providing the backup generating capacity is the reserve cost. The reserve required also depends upon the amount of time that the new unit is required to run and the capability of existing units to back it up. Reserve cost is therefore a function both of the characteristics of the new unit and the characteristics of the existing system.

It is usual for the reserve capacity of a base load unit to be provided by low capital cost units with relatively low efficiency. Alternatively in the case of an interconnected system the backup may be provided by energy purchases. The differential in cost between producing energy by the base load unit and its replacement is the replacement energy cost. In the context of residual fuel fired diesels in developing countries, there is almost always a replacement energy cost since the residual fuel fired engines are usually the base load units.

The concept of effective capacity 1 helps us to quantify the reserve cost and in this special application, the parallel evaluation of low and medium speed diesels, the replacement energy cost. The replacement energy cost is included since the use of the concept ensures that enough plant of the same efficiency is provided to cover reserve requirements.

The effective capacity of a generating unit is the amount by which the existing system load may be increased, without violating the target reliability level, after addition of the new unit to the system.

We must emphasize that in planning or in bid evaluation the primary concern is the performance of the power system after the addition of a generating unit and not the performance of that unit in isolation. If the existing system is ignored during the decision to purchase a new unit, there is no assurance that the objective of the plant addition will be met.

It is especially important that we consider the consequences of reliability in the comparison of medium speed four stroke and low speed two stroke engines, since there is evidence to suggest that there are significant differences in the reliability of these engine types when burning residual fuel.

We will show in the following paragraphs how we can estimate the number of units and capacity of either type of engine required to satisfy the effective capacity needs of a system. This is best done by first reviewing the generation expansion planning process.

6.2.2 Generation Expansion Planning

When planning generation expansion, we try to develop a sequence of generating plant additions which for the least cost will provide a predetermined standard of service over the selected time period. The additions are chosen from the standard equipment lines of various manufacturers.

The standard of service may be set to maintain or improve upon the service presently offered. It is becoming
more usual, however, to attempt to equate the incremental cost of reliability with the cost to the economy of failing to supply the required energy.1/

Once a target reliability level is established for the generating system, we select a number of technically feasible alternative expansion plans and test them to ensure that within reasonable limits they all provide the same quality of service. We then determine the total life cycle cost of each alternative and select the least cost option. The costs used at this stage are budgetary estimates based on past experience.

Deterministic methods are still used by some utilities and consultants to equate the quality of service provided by alternatives. These methods are based on the objective of maintaining a certain level of reserve generation in excess of the peak demand. The three most popular are:

- Reserve equal to various combinations of units on the system. For example, the largest and smallest, the two largest, etc.
- Percent reserve based on the peak demand.
- Percent reserve based on the installed capacity.

Despite the advantages that these methods are easily understood and explained to non-technical people, there are two serious disadvantages, especially for small utilities using diesel plant:

- The deterministic methods are subjective and results vary depending upon which criterion is chosen.
- They do not take into account the fact that the reliability of diesel engines may vary considerably depending

upon their type (two stroke low speed vs. four stroke medium speed) and the quality of fuel burned.

The alternative to the above deterministic methods is the use of probabilistic methods whose main disadvantages are:

- They are difficult to explain to non-technical people.
- They require a good historical data base to facilitate the estimation of the various probabilities required as input data.

The most used of the probabilistic indices is the Loss of Load Expectation (LOLE) often referred to as the Loss of Load Probability (LOLP). The calculation of this parameter involves the convolution of two mathematical models, a load model and a generating system capacity model. The load model is a table consisting of the forecasted system loads and the probability of their occurrence, usually on a daily basis. The capacity model is a tabulation of probabilities for the availability of various levels of generating capacity. Allowance is made for those generating units which are unavailable due either to planned maintenance or to random forced outages.

The Loss of Load Expectation is the expected number of days per year that the available capacity is less than the daily peak load. It is calculated as the sum of the probabilities of generation shortage for each daily peak over the period.

The method for using the LOLE index to equate alternatives prior to life cycle costing involves plotting a curve of the system risk level (LOLE in days/year) against system peak load. If this is done for the existing system, and for the system

with various alternatives added, we can determine the benefit of each addition. The benefit to the system of the additional unit is the effective capacity of that unit (see figure 6.2).

![Graph showing effective capacity of added unit]

Figure 6.2: Effective Capacity of Added Unit

The effective capacity of the new unit depends upon its forced outage rate, its capacity relative to the capacity of the system and the forced outage rates and capacities of the units comprising the system prior to the addition of the new generation. The effective capacity is usually less than the nameplate capacity.
Garver derived an equation which may be used to estimate the effective capacity of a generating unit addition to a system without computing the new risk curve. He defined a parameter 'm' (with units of megawatts) which contains the information we need about the existing system. The parameter 'm' is defined as the amount by which the system reserve must change to change the risk level 'e' times where 'e' is the base of the natural logarithm. The equation for effective capacity is:

\[ c^* = c - m \ln \left( (1-r) + r \frac{e^c}{m} \right) \] .................(6.1)

where

\( c^* \) is the effective capacity of the added generating plant, in megawatts.

\( c \) is the site rated capacity of the new unit, in megawatts.

\( r \) is the forced outage rate of the new unit expressed in per unit.

\( m \) is a parameter defining the reliability characteristics of the existing system (with units of megawatts).

The value of 'm' may be derived from the slope of the risk level - reserve curve (see Appendix A for details of the calculation of 'm').

The forced outage rate 'r' is the probability of the existence of a forced outage of the unit. A good estimate for a base load unit is given by the equation:

\[ r = \frac{\text{FOH}}{\text{SH} + \text{FOH}} \] ..............(6.2)

where

\( \text{FOH} \) - is the total forced outage hours over the period (usually a year).

\( \text{SH} \) - is service hours for the period.

6.2.3 Application of 'Effective Capacity' to Bid Evaluation

The concepts of the system parameter 'm' and the effective capacity c*, outlined in the preceding paragraph, are powerful tools for the bid evaluation process. The parameter 'm' is a vehicle by which the bidder can be informed of the reliability characteristics of the existing system. The effective capacity c* indicates the value, to the purchaser, of the offered plant.

To enable bids to be compared on the basis of effective capacity, potential suppliers must be provided with the effective capacity requirement and the value of m for the system. In addition they must be given the forced outage rates for various plant types and practical limits relating to the number of capacity of units that may be used to satisfy the effective capacity requirement.

The use of effective capacity for bidding is best explained by an example.

The system supplying an island has an installed capacity of 94 MW consisting of a mix of diesel, gas turbine and steam plant. The load carrying capability of the existing system at an LOLE of one day per year is 44 MW (see figure 6-3). The value of the parameter 'm' for the system is 6.2 MW (see Appendix A for method of calculating 'm').

The effective capacity addition required is 20 MW ± 1 MW to raise the load carrying capability of the system, at an LOLE of one day/year, to 64 MW.
Figure 6.3: Required Effective Capacity

Two possible options for a supplier to meet the required effective capacity could be:

OPTION 1

Low speed two stroke diesel generators with a short time peaking capacity of 12 MW each. Forced outage rate \( r = 0.05 \) per unit. 1/

1/ The forced outage rates used here are for the purpose of demonstrating the technique. Actual values should be assigned by the engineer preparing the specification based on the best available data.
OPTION 2

Medium speed four stroke diesel generators with a short time peaking capacity of 7 MW each. Forced outage rate $r = 0.18$ per unit.

There are of course many other possible solutions, for example, using smaller low speed diesels or larger medium speed diesels, but the above are adequate to demonstrate the technique.

For the low speed diesel option (option 1), when we add the first unit the effective capacity, using equation 6.1, is:

$$c^* = 12 - 6.2 \ln \left\{ (1-0.05) + 0.05 e^{12/6.2} \right\} = 10.4 \text{ MW}$$

We now estimate the new value of 'm' for the system after the addition of the first unit, using the approximate equation:

$$m_{\text{new}} = m_{\text{old}} + rc \hspace{1cm} \text{(6.3)}$$

where

- $r$ is the forced outage rate of the unit added
- $c$ is the capacity (nameplate peaking) of the unit added

In this case,

$$m_{\text{new}} = 6.2 + 0.05 \times 12$$

$$= 6.8$$

The effective capacity of the second unit is now calculated to be:

$$c_2^* = 12 - 6.8 \ln \left\{ (1-0.05) + 0.05 e^{12/6.8} \right\}$$

$$= 10.5 \text{ MW}$$

The total effective capacity added is therefore:

$$10.4 + 10.5 = 20.9 \text{ MW}$$
Thus a nameplate peaking capacity of 24 MW of the low speed two stroke diesel plant is required to obtain an effective capacity of 20.9 MW on this power system.

The process of adding the two units is shown in figure 6.4. The curves used in figure 6.4 are those generated by using a computer program, and would not normally be available for bid evaluation. There is close agreement between the actual values shown by these curves and the values obtained using the approximate method above.

Figure 6.4:  Sequence of Unit Additions
We now estimate the capacity (nameplate peaking) of medium speed four stroke diesel required to supply the required effective capacity of 20 MW. Taking Option 2 we have after addition of the first unit:

\[ c_1^* = 7 - 6.2 \ln \{(1-0.18) + (0.18)e^{7/6.2}\} \]
\[ = 5 \text{ MW} \]

Using equation 6.3 to estimate the new 'm' of the system we have:

\[ m_{\text{new}} = 6.2 + 0.18 \times 7 \]
\[ = 7.5 \text{ MW} \]

The effective capacity of the second unit added is:

\[ c_2^* = 7 - 7.5 \ln \{(1-0.18) + (0.18)e^{7/7.5}\} \]
\[ = 5.2 \text{ MW} \]

The new 'm' after this addition is:

\[ m_{\text{new}} = 7.5 + 0.18 \times 7 \]
\[ = 8.8 \text{ MW} \]

The third unit added has an effective capacity of:

\[ c_3^* = 7 - 8.8 \ln \{(1-0.18) + (0.18)e^{7/8.8}\} \]
\[ = 5.3 \text{ MW} \]

After adding a total of 21 MW (nameplate capacity) we have achieved an effective capacity of only 15.5 MW. A fourth unit is therefore required.

The new system 'm' is given by:

\[ m_{\text{new}} = 8.8 + 0.18 \times 7 \]
\[ = 10 \]

\[ c_4^* = 7 - 10 \ln \{(1-0.18) + 0.18e^{7/10}\} \]
\[ = 5.3 \text{ MW} \]

The total effective capacity is thus 20.8 MW and it requires the addition of 28 MW (nameplate peaking capacity) of medium speed four stroke plant.
Assume that the cost of the low speed plant is U.S. $1,200.00 per kW and the medium speed plant is U.S. $700.00 per kW based on the nameplate maximum continuous site rating. Assume also that the short time peaking rating is 10% over the maximum continuous rating. Then the cost of the low speed plant is $26,160,000 and that of the medium speed $17,920,000.

The base price thus obtained is further adjusted by various weighting factors including the expected useful life span of the plant.

For practical purposes, limits must be put on the maximum number of individual units allowed. In the example shown above more than four units would probably have been unacceptable because of the logistics of dealing with large numbers of valves and pistons. It is also usually desirable to specify, in the case of multiple units, that they should all be of the same type and size.

The results of the approximate effective capacity calculations are less accurate in situations where the generating unit being added has a high forced outage rate or is large compared to the existing system. Appendix A shows a method of modifying equation (6.1) to provide acceptable results for these situations.

6.3 Fuel Consumption, Generator Losses, and Transformer Losses

6.3.1 General

Considering the high cost of fuel, both present and predicted, small reductions in fuel consumption or electrical losses can result in savings which, over the useful life of a plant are significant relative to its capital cost. For example,
a ten percent improvement in the fuel consumption of a diesel generating unit, from say 220 grams/kWh to 200 grams/kWh, will result in an annual saving of U.S. $264,000.00. (Based on a 10 MW unit run for 7000 hrs. per year on fuel costing U.S. $30.00 per barrel).

Even if the capital cost of the plan is as high as U.S. $1200 per kilowatt, the saving over five years at an discount rate of 12% is equivalent to $95.00 per kilowatt, about 8% of the capital cost. Looking at this another way, we can justify spending up to 8% more at the time of purchase to achieve a 10% reduction in fuel consumption.

Significant savings can also be realized by the use of a more efficient main power transformer. A reduction of the losses through the transformer by as little as 0.07% will result in savings, over a five year period, as high as 15% of its capital cost. It is clear therefore that fuel consumption and energy losses in a plant warrant careful attention in the evaluation of bids.

The flow of energy through a typical diesel generating unit is shown, in simplified form, in figure 6-5. It is the desire of the purchaser to maximize the quantity of electrical energy (the product) out at for a given quantity of fuel (the raw material) in at . Steam or hot water is a byproduct for which there may be a market.

By far the major source of energy losses is the engine. About 60% of the energy entering at is unavailable for doing work. This is accounted for in the bid evaluation by putting a value on fuel consumption. The other items which are usually quantified are generator losses, energy consumed by the 

1/ A power transformer is not always included if there is spare transformer capacity at an existing installation.
auxiliaries, and losses in the main power transformer. Losses in fuel pre-processing (A to C), which are as high as 3% of purchased fuel, are not usually accounted for since these are similar for most engines. They may be reduced by the use of an incinerator shown in figure 6-5. The incinerator also solves the environmental problem of sludge disposal.

Figure 6.5: Typical Plant Block Diagram

To account for the above elements of efficiency in bid evaluation, we must determine the differential life cycle cost, for each alternative, relative to a reference set of efficiencies. These are arbitrary, and relative values are used instead of absolute values to keep the numbers workable. In the comparison of bids it is the relative values that are significant. The differential costs are then added to the bid prices.
6.3.2 Value of Efficiency

Since the highest losses occur in the engine, we will outline the methods of determining the monetary value of relative efficiency by referring to the calculation for the engine. The procedure is similar for the generator, transformer, etc.

First, a note about units of measurement. The fuel consumption of a generating unit is quoted usually as a specific fuel oil consumption (SFOC) with units of grams per kilowatt-hour or pounds per kilowatt-hour. It may also be quoted as a heat rate with units of Btu per kilowatt-hour or kilojoules per kilowatt-hour.

Before alternatives are compared using any of the above it is important to ensure that the ambient conditions and the points in the process at which measurements are taken are defined. If the heat rate is being used it is also necessary to define the calorific value of the fuel. These details are dealt with in section 7. We will use grams/kWh for the SFOC in the following discussion.

We first choose a reference SFOC, which is near to the values expected, say 210 grams/kWh.

The annual differential fuel cost for each alternative is given by:

\[ C = (E_i - E_o) \times U \times F \] .............................. (6.4)

\( E_i \) is the SFOC of the \( i \)th alternative (grams/kWh)
\( E_o \) is the reference SFOC (grams/kWh)
\( U \) is the energy generated annually (kWh/yr)
\( F \) is the fuel cost ($/gram)
\( C \) is positive or negative depending upon whether the alternative considered has a higher or lower fuel consumption than the reference fuel consumption of 200 g/kWh
Since the heat rate curve of a diesel is not flat, (see figure 6-6), $E_i$ must be defined as a weighted average SFOC to account for differences in fuel consumption at various load points.

![Figure 6.6: Typical Heat Rate Curve](image)

The weighting depends upon the power system in which the unit will be used, especially on the load factor of the system. A typical weighting is:

$$E_i = \frac{1E_{50\%} + 4E_{75\%} + 4E_{100\%}}{9} \quad (6-5)$$

The energy production depends upon the load factor of the system, the availability of the unit and its ranking in the dispatch list. For a baseload unit, 7000 hours per year at 85 to 90 percent of full load is not unreasonable. The number of hours per year may be reduced toward the end of the economic life of the unit.

The cost of fuel $F$ which is expressed in constant dollars should be based on the world market price and must be free
of all taxes and subsidies to reflect the true economic cost. Fuel prices should be escalated only by the amount by which the price is expected to increase above the average inflation level. (i.e. only escalation in real terms is allowed). Since some residual fuel fired engines require distillate fuel for startup and shutdown, the percentage of distillate fuel required over the year should be used to weight the cost of fuel.

Having determined the differential fuel cost for each year of the economic life of the plant, we need to determine the cumulative present value of the differential, given by:

\[
\text{Cumulative Present Value} = \sum_{r=1}^{n} C_r \cdot D_r \quad \ldots \ldots (6.6)
\]

where

- \( C_r \) is the differential fuel cost in year \( r \).
- \( D_r \) is the discount factor for year \( r \) at the chosen discount rate.

If we assume the annual production of energy to be constant we simply multiply the annual differential fuel cost by the present worth of an annuity factor \( \frac{1}{r} \) for the appropriate number of years. Escalation (in real terms) of the fuel is accommodated by varying the present worth factor. For example, if the annual differential cost is \( C_r \) the economic life of the plant is 15 years and the discount rate is 12\%, the cumulative present worth of the differential fuel cost is 6.8 x \( C_r \).

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1/ See Compounding and Discounting Tables for Project Evaluation - A World Bank Publication, Distributed by the Johns Hopkins press.
6.4 Lubricating Oil Consumption

6.4.1 General

Lubricating oil is consumed in two ways by an engine. It is burned in the cylinders; it is contaminated or loses its efficacy and needs to be replaced. There are differences in the design of four stroke medium speed and two stroke low speed engines which affect the rate of use of lubricating oil. In general, the four stroke engine, in the capacity range of interest, burns about 1.4 g/kWh, and the two stroke between 0.6 and 0.8 g/kWh. We recommend that the lube oil burned be included in the bid evaluation as a fixed amount based on experience. The amount is controllable, in the case of the low speed engine, and the consequence of inadequate lubrication is increased wear, which is not readily detectable during acceptance testing.

The relative frequency of complete oil changes and quality of oil required are often ignored. They are both affected by the design of the two types of engine. These differences and their consequences are outlined in the following paragraphs.

6.4.2 Effect of Engine Design on Lubricating Oil Consumption

Most two stroke low speed engines are designed with a crosshead bearing which facilitates isolation of the combustion spaces from the crankcase by a diaphragm. Two lubricating oil circuits are used, one for cylinder lubrication and one for crankcase lubrication.

Oil is injected into the cylinder for lubrication, cooling and to neutralize the acid products of combustion which otherwise would cause corrosion. This oil must have a high TBN
number (measure of basicity) especially if fuels high in sulphur are burned. The oil injected into the cylinder is burned, at a rate which is controllable, and needs to be continually replaced. If sufficient oil is not injected, high wear rates result.

The oil in the crankcase, isolated from the combustion process, is consumed at a very low rate and will last for long periods, as long as 40 000 hours. Since its only function is lubrication, it is a less expensive grade of oil than that used for cylinder lubrication.

The combustion spaces of the four stroke medium speed engine are not effectively isolated from the crankcase. Consequently, the entire charge of oil is contaminated by the products of combustion. The entire charge must be high quality oil with a relatively high TBN number (not usually as high as the cylinder oil for the two stroke).

There is no direct control over the amount of lubricating oil burned, although some manufacturers inject oil directly into the cylinder rather than relying on splash lubrication. The oil, if untreated, needs to be changed every 4 000 to 5 000 hours.

6.4.3 Indicators of the Need for a Change of Oil

The most common conditions which signal the need for a change of oil are:

- The presence of excessive solids.
- The loss of its detergent properties.
- The presence of acid.
- Water contamination causing it to emulsify.
The above are detected by analysis of the oil which should be done at regular intervals. The consequences of ignoring the above signals vary between increased wear of the engine and catastrophic breakdown.

6.4.4 Measures to Increase the Life of Lubricating Oil

The presence of excessive solids is usually the condition which occurs first. The life of a charge of oil in a medium speed engine can be increased from the average 4 000 to 5 000 hours to as much as 10 000 hours by proper purification. An adequately sized centrifuge along with filters will remove solids and water and thus increase the useful life of the oil.

6.4.5 Effect of Lubricating Oil Consumption on Fuel Consumption

The lubricating oil consumed in the cylinder replaces an almost equivalent amount of fuel. The engineer supervising a specific fuel oil consumption test should be aware of this and should ensure that excessive cylinder lubricating oil is not being injected to enhance the apparent efficiency of the engine. This is especially important if the specific fuel oil consumption has been guaranteed within close tolerances.

6.4.6 Value of Lubricating Oil Consumption in Bid Evaluation

It may be counterproductive to require a supplier to guarantee lube oil consumption (oil burned in cylinder) since, in the case of the low speed engine, it is possible to obtain low values at the expense of future wear. The amount consumed should
be checked during acceptance testing to ensure that it is not excessive. A suitable test procedure is described in ISO Standard 3046.

The bid evaluation should include the relative cost of oil required for complete oil changes, due to contamination, over the life of the plant. It is best to base this assessment on previous experience and take into account the quality of the lubricating oil purification plant included in the tender.

6.5 Maintenance Cost

6.5.1 General

For the purpose of bid evaluation, we are concerned with the relative cost of maintenance associated with the various plants offered. The absolute cost of maintenance has been as low as 4% and as high as 30% of the total annual cost of producing electricity using diesel plant. Although much of the spread in cost is caused by factors relating to the location of the plant, there is likely to be a significant spread between alternatives offered for a specific application.

It is difficult to accurately predict the maintenance cost for a plant at the time of bid evaluation. Supplier's claims are not verifiable at this time, and therefore are useless for evaluation.

It would appear that the best estimate of maintenance cost, is the cost of a maintenance contract with the supplier. A maintenance contract, which should be covered by a performance bond, reflects the maintenance cost to which the supplier is willing to commit himself, and is a fixed cost to the purchaser for the duration of the contract.
In the event that it is impossible to obtain a maintenance contract, relative maintenance cost may be estimated based on historical data for similar installations.

6.5.2 Factors Influencing Cost of Maintenance

The maintenance cost consists of labour, supervision and spare part costs. The cost of spare parts is set by the manufacturer and is influenced by the location of the plant. The labour cost depends upon the location of the plant and the level of skill available.

For a given location and a given quality offered, the major factors influencing the cost of maintenance are:

- Design of the engine (quality of lubrication, materials used, maintainability, etc.)
- The number of exhaust valves.
- The number of injectors.
- Time between major overhauls.

The number of injectors and exhaust valves (providing exhaust valves are used) is proportional to the number of cylinders.

6.5.3 Maintenance Cost from Maintenance Contract

A maintenance contract usually consists of provisions for the supply of spare parts and maintenance supervision for a period of three to five years. The annual cost of local labour may be estimated and added to the annual cost of the contract to yield the total cost of maintenance. It is essential that the period of the maintenance contract quoted be long enough to cover at least one major overhaul.
The main advantage of using a maintenance contract to assess maintenance cost is that it includes the cost of repairs resulting from breakdown.

6.5.4 Maintenance Cost Based on Number of Components

A rough indication of the cost of maintenance may be obtained by comparing the number of components with high repair requirements. If it is necessary to use this approach, a points system is recommended, where for example, an engine with few exhaust valves is given a high rating and one with many for the same power output a low rating. The final points accumulated may then be used to weight the bid price.

6.6 Arrangements for Training

Training arrangements are best treated in a qualitative way in the bid evaluation. Attempts to identify training costs separately and to use them in the evaluation may be counter-productive since there is no simple way of measuring the effectiveness of training provided.

Ideally we would prefer a supplier to train maintenance and operating staff and to certify these people as being competent to perform their job function. It would be difficult, however, for the supplier to bind himself to such an arrangement since he has no control over the educational level and aptitude of the personnel provided for training. On the other hand, if we require the supplier, in a competitive situation, to quote a price per hour of training supplied, we may not obtain the services of his most competent (and usually highest priced) people.
A possible approach to evaluating training, therefore, is simply to ensure that the bid includes training arrangements within some broad outlines. The outlines, provided in the specification, should include a list of the job functions and number of people to be trained, and the minimum number of hours of training required.

The training offered should have a practical bias. Usually it is provided in the manufacturer's works. It is imperative that the maintenance personnel assist in the final assembly of the engine, and the operating personnel in the initial runs. This gives them the opportunity to become familiar with the peculiarities of the specific engine.

Finally, training should not be confused with the maintenance and operating assistance contract. If the supplier provides supervisory personnel under such a contract, their primary function is to ensure proper operation and maintenance of the engine. Any training which may occur in this process is incidental. The purchaser's operating and maintenance staff should be adequately trained before the plant is put into commercial operation.

6.7 Mechanical Design Features

6.7.1 General

In a bid evaluation, the main distinction between the quality of service provided by medium four stroke engines and low speed two stroke engines is made by comparing the effective capacity of each when added to the existing power system (see section 6.3.2). We use a mean forced outage rate derived from historical data of a group of each of the two generic engine types for the calculation of the effective capacity. Consequently, the calculation does not account for differences in the expected performance of engines within each group.
By weighting each bid price with points awarded on the basis of various mechanical design features, we are able to account for some of these differences, and thus refine our evaluation. The design features chosen are those which have the greatest effect on the ability of the plant to operate reliably using poor quality residual fuel. We are therefore able to give due credit to manufacturers who, by virtue of superior design and development, have overcome some of the problems of using residual fuel.

In the following paragraphs we will identify some of the more important design features, and suggest a method of awarding points. Relative to the overall bid evaluation, the adjustments for mechanical design features should change the bid price by a maximum of about 5%. A purchaser may change this limit, at the time of preparing the specification, if the value of these mechanical design features is perceived to be higher or lower than 5% of the overall plant price.

6.7.2 Mechanical Design Evaluation Data

The engine data (table 6-7) should be stated at the maximum continuous rating of the engine for the site conditions specified. As can be seen from the evaluation factors, certain items influence performance and engine service life more than others.

Since there is continuous engine development work in progress, it may be necessary to change the emphasis on various design features as experience dictates. The best reference for assigning evaluation factors is an identical engine with a good performance record under similar environmental conditions and burning similar fuel.
Although the performance of an engine is dictated by a complex interrelationship of the design parameters listed, a simple weighting system based on the individual parameters will yield adequate indications of the quality of the engine.

Table 6.7: Mechanical Design Evaluation Data

<table>
<thead>
<tr>
<th>Engine Data</th>
<th>Evaluation Factor</th>
<th>Evaluation Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exhaust valve seat or valve port metal temperature</td>
<td>0 to 70</td>
<td>A</td>
</tr>
<tr>
<td>Brake mean effective pressure</td>
<td>0 to 60</td>
<td>A</td>
</tr>
<tr>
<td>Mean piston speed</td>
<td>0 to 50</td>
<td>A</td>
</tr>
<tr>
<td>Excess (continuous) brake horsepower over net brake horsepower required to maintain maximum continuous power at generator terminals</td>
<td>0 to 40</td>
<td>A</td>
</tr>
<tr>
<td>Fuel injection pump pressure</td>
<td>0 to 30</td>
<td>A</td>
</tr>
<tr>
<td>Cylinder arrangement (in-line or Vee)</td>
<td>0 to 20</td>
<td>B</td>
</tr>
</tbody>
</table>

6.7.3 Evaluation Methodology

METHOD A:

The evaluation factor is assigned according to the range of values given for the various engines offered. The engine with the highest value of the parameter considered would be awarded zero and that with the lowest, the maximum evaluation factor listed. Those engines between the high and low would be pro-rated. For example, if we have four tenders with mean pis-
ton speeds of 6.3, 7.8, 8.0, and 8.2 meters per second respectively, the award of evaluation factors would be:

<table>
<thead>
<tr>
<th>Piston Speed (m/s)</th>
<th>Evaluation Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.3</td>
<td>50</td>
</tr>
<tr>
<td>7.8</td>
<td>11</td>
</tr>
<tr>
<td>8.0</td>
<td>5</td>
</tr>
<tr>
<td>8.2</td>
<td>0</td>
</tr>
</tbody>
</table>

**METHOD B:**

In-line engines will be awarded 20 points and Vee engines zero. This reflects the simplicity and ease of maintenance inherent in the in-line engine design.

After the points are awarded for each engine, they would be expressed as a per unit of the maximum number of points possible and applied to the portion of the purchase price being weighted. The resulting number is subtracted from the base price. For example, if an engine rated a total of 200 points out of 270, or 0.74 per unit and if 5% of the base price of $6,000,000.00 were to be adjusted, then the adjustment is $(0.74 \times 0.05 \times 6,000,000) = $222,000.00. This value of $222,000.00 is the worth of a superior engine design to the purchaser and is subtracted from the base price of $6,000,000.00 prior to comparison of the bids.

**6.8 Equipment Equalization**

The equipment equalization portion of the bid evaluation is used to adjust the bids to reflect departures from the supply of auxiliary equipment listed in the specification. The prices used for this equalization should be those quoted by the supplier, and in cases where a separate price is not quoted, a reasonable price may be assigned by the evaluator.
The equalization is done prior to other bid evaluation adjustments. It is applied to the total price of the offered package.

6.9 Prime Contractor for 'Turnkey' Package

Since the engine is the most complex and expensive part of the entire power plant, it is usually advantageous to have the engine manufacturer as the leader of the group putting together a 'turnkey' package. Response to queries and attention to problems with the engine are usually faster and the supplier has an interest in the long term performance of the plant.

The value, to the purchaser, of having the engine manufacturer as leader varies from case to case, but is unlikely to exceed one percent of the bid price. The assigned value is subtracted from the bid price in those cases where the engine manufacturer is leader.

6.10 Similarity to Existing Engines

It is desirable where possible to avoid mixing engine types in the same plant. Maintenance and Operating personnel who have become familiar with one type of engine often make mistakes if another type of engine is added to the same plant. An adjustment should be made to the bid price in favor of plant which is similar to that existing.

6.11 Supplier's Past Performance

A supplier who responds quickly and attends to the needs of a purchaser competently can save the purchaser time and money in the execution of a contract. Such a supplier should be re-
warded in the bid evaluation. Some of the marks of a good supplier are:

- Accurate pricing of bid.
- Delivery on schedule.
- Quick and efficient response to requests for modifications.
- Easy and amicable settlement of contractural differences.
- Good communication.
- Clear and precise drawings and manuals.
- Interest in communicating latest technological developments to the purchaser.

Benefits for the above can be awarded only if a record of previous dealings with the supplier has been kept. Some consultants, having dealt with a wide cross section of the suppliers, can provide a reliable comparison. 1/

The value of the supplier's performance is relatively small in the overall evaluation and should usually affect only about one to two percent of the bid price.

6.12 Engine Operating Experience

6.12.1 General

We must be cautious when selecting an engine for applications in which unreliable performance would be disastrous, such as for power generation in a developing country. The best indicator of whether or not an engine will perform reliably in a proposed application is the operating history of identical engines working under the same conditions. Another

indicator of reliability, commonly presented by suppliers, is the result of development testing. These results are inadequate for predicting reliability mainly because all conditions in the field and their complex interrelationships cannot be duplicated in the laboratory. Prototypes 1/ therefore are usually unacceptable, and verifiable operating experience is a mandatory requirement in the evaluation of bids. Only in extenuating circumstances should a prototype be considered, and then only with insured guarantees from the supplier, including compensation for loss of production due to engine failure.

To check if the experience presented in support of a tendered engine is adequate, an evaluator must visit the plants cited as references and examine them with reference to the following:

- A definition of reliable operation.
- A definition of allowable differences between the design of the tendered engine and reference engines.
- A definition of allowable variations between the projected operating conditions of the proposed engine and those of the reference engines.

We will outline the considerations leading up to the above definitions in the following paragraphs.

6.12.2 Reliable Operation

We must have some benchmark against which we compare the performance of an engine presented as a reference

1/ Prototypes in this context include engines which have been dependable in the past, but are tendered with a critical design change (e.g. an increase in the bmep, or the use of residual fuel for the first time). However, since rapid developments in engine design are occurring some flexibility in the definition of prototypes may be required.
by the supplier. The benchmark must be set to reflect the average performance of the generic type of engine under consideration, since our planning is done using mean statistical values. The implication is that if the engine being considered has performed at least as well as the mean of the group, the performance of the proposed engine is likely to be similar and thus conform to the results predicted by the expansion planning study which triggered the purchase.

To set the benchmark for assessing reliability or the quality of service provided by the reference engines we must specify:

- The number of hours of operation of the engine.
- The elapsed time over which the operating hours were accrued.
- The loads at which the engine operated.
- The total energy production.
- The number of outages experienced.
- The maximum permissible outage time for a single incident (this defines the magnitude of incidents).
- The availability of the engine.
- The forced outage rate of the engine (probability of existence of an outage state).

All of the above parameters which should be included in the specifications, must be reasonable. The measurements of reliability: number of outages, etc., should be set about the mean for the type of engine considered. For example, a survey of residual fuel fired medium speed four stroke engines in developing countries yielded a mean availability of 73%. To require demonstration of availabilities significantly higher would be unreasonable and would severely circumscribe the available pool of bidders.

6.12.3 Differences in Engines

It is unlikely that the engine tendered will be identical to those listed as references. We must ensure that any variations are those which have no potential to affect the inherent reliability of the engine. Permissible variations are subject to the judgement of the engineer and must be included in the specification.

To facilitate this control two things must be done. First we must classify design variations according to function. Second, we must establish a coding system to identify criteria for the acceptability of variations. The following example illustrates both of these steps.

Three categories for acceptability of change are:

A - any variation is acceptable provided it does not cause deviations from the functional requirements.
B - a variation is acceptable provided it has the approval of the engineer.
C - no variations are permissible.

A possible functional classification is as follows:

<table>
<thead>
<tr>
<th>DESIGN CONSTRAINTS</th>
<th>ACCEPTABILITY OF VARIATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>bmep</td>
<td>C</td>
</tr>
<tr>
<td>Rotational Speed</td>
<td>C</td>
</tr>
<tr>
<td>Number of Cylinders</td>
<td>C</td>
</tr>
<tr>
<td>Bore</td>
<td>C</td>
</tr>
<tr>
<td>Stroke</td>
<td>C</td>
</tr>
</tbody>
</table>
ACCEPTABILITY OF VARIATION

DESIGN DETAILS - physical dimensions, materials and methods of fabrication for:

Bedplate C
Box frame C
Cylinder Block (configuration:
  Vee vs. in-line) C
Cylinder liners B
Cylinder heads C
Foundation A
Crankshaft C
Bearings B
Pistons C
Piston rings B
Connecting rods C
Valves and associated equipment B
Fuel System B
Cooling System A
Lubrication System A
Air intake and turbocharging system A
Exhaust gas system A
Instrumentation B
Controls A

6.12.4 Differences in Operating Conditions

Various operating conditions affect the performance and reliability of an engine. If the conditions at the proposed plant are not identical to those at the reference plant, we must be aware of the implications of each variation to judge whether or not the experience proffered is valid. The most significant operating conditions are:
• Fuel quality.
• Load pattern.
• Ambient conditions (temperature, pressure and humidity).
• Presence of airborne contaminants (e.g. sand or salt, salt spray).
• Management of the plant.

It is desirable that there be close similarities between the fuel proposed in the new plant and that used in the reference plant. The majority of the problems encountered in operating residual fuel fired engines are caused by properties of the fuel and contaminants associated with it. Currently fuel treatment techniques, namely filtering, centrifuging and homogenizing, do not remove vanadium, the chief contributor to valve failures. The vanadium is associated with the fuel as an organometallic compound and thus cannot be removed by mechanical means. As a result the engine must be capable of reliable operation in the presence of vanadium contamination, and any other properties of the fuel which cannot be modified by the treatment process. The fuel used must therefore be similar, so that we may judge the chances of success of a proposed engine based on the behaviour of the reference engines.

The load cycles applied to the engine are important. The results of loading, however, are predictable and may be accommodated once they are recognized. For example, an engine used for peaking duty is likely to suffer from problems associated with part load operation and frequent thermal cycling. Part load operation promotes incomplete combustion which among other things causes coking and a buildup of asphaltenes. Thermal cycling causes problems with joints, especially in the exhaust system. If we are purchasing an engine for base loading, and the reference engine was used for peaking, we would ignore these problems since they would be unlikely to show up in base load operation.
Ambient conditions and the presence of airborne contaminants are catered for by derating, changing cooling requirements and filtering combustion air as applicable. These conditions therefore need not be identical in the proposed and reference plants.

The quality of plant management is a variable which must be accounted for when considering reference engines. Ideally we would like to inspect a reference plant where the calibre of operating and maintenance is similar to that expected in the proposed plant. If this is not possible, an experienced evaluator can assess the possible contribution of operation and maintenance practices to the performance of the reference plant.

6.12.5 Procedure for Investigating Experience

The evaluator must visit and rigorously examine the operating history of at least one of the reference plants listed by each potential supplier. A standard form should be used to ensure a systematic investigation of the relevant parameters. To ensure that the information collected remains confidential and is without bias it is essential that no supplier's representatives be present.

The evaluator should first establish whether or not the plant visited satisfies the criteria for a reference. Then he should determine the degree of success of the operation. If either of these is not satisfactory, the other plants listed by the supplier should be closely examined.

Finally, every effort should be made to minimize the inconvenience to the personnel of the reference plants, since visits for confirmation of experience disturb their normal operations.
6.12.6 Marine Versus Land Based Experience

Suppliers whose engines lack adequate operating experience in land based applications often cite shipboard experience to demonstrate dependability. There is some difficulty in using this experience directly since the definition of reliability for power generation is different to that for ship propulsion. Although more judgement is required on the part of the evaluator, the experience is relevant and may be used. The two conditions which must be similar for the proposed and reference engines are the fuel used and the loading conditions. The requirement for similarity of fuel is as stringent as for comparing two land based plants. With reference to loading, a good rule of thumb is that the operation of the engine on an oceangoing vessel is similar to a base load plant, whereas that of a ship doing short runs and frequent manoeuvering is similar to a peaking plant.

6.13 Effective Capacity Requirement

The specification will require suppliers to offer plant to yield an effective capacity (see section 3.3.2) within a given narrow range. This requirement is mandatory on the lower limit of the range given. For example, if an effective capacity of 10 ± 1 MW is required, anything less than 9 MW will not satisfy the requirements upon which the economic decision to buy plant is based. Offers over the top limit should be considered only if the total evaluated project price is the least of those tendered.

Although there is economy of scale as plant size increases, we must satisfy only the needs of the system. Thus we cannot consider a plant larger than the one we require simply because it is cheaper on a per kilowatt basis.
6.14 Basic Warranty

Each bid must include a warranty which offers at least the level of protection commonly offered by suppliers. This is a mandatory requirement, and any bid which excludes a warranty should be rejected.

Most suppliers offer a warranty of twelve months duration which covers the replacement of parts which fail because of defective materials or workmanship. Secondary damage is usually excluded. For example, if a valve breaks and fragments go through the turbocharger wrecking it, the supplier's responsibility, as defined by the warranty, stops at replacing the valve. Good suppliers usually go beyond this and offer concessions to assist in correcting the secondary damage.

If in the bid evaluation it is noted that a supplier has offered more than the basic warranty coverage, the value of the extra coverage should be assessed and a benefit given. One way of assessing the value of extra coverage is to use the cost of insurance to cover the incidents which are included in excess of the normal warranty.

In cases where a maintenance contract is included, we must be careful to determine if there is overlap with the warranty. This is necessary to ensure that all potential failures are covered.

6.15 Spare Parts

The inclusion of spare parts in a bid is usually a mandatory requirement. There are two main reasons for this requirement. First, it ensures that spare parts are available on site for the initial period of operation (three to five years). In this period a pattern of use can be established to guide further
purchases. Second, it fixes the price of spares for this period and establishes a benchmark for future negotiations if the supplier attempts to increase the price of spares unreasonably.

There are a few practical details that must be attended to. The minimum quantity of spares required should be listed in the specification with allowance for suggestions by the supplier. The minimum amounts, for the engine, may be based on the requirements of a licensing authority such as the American Bureau of Shipping, Norske Veritas or Lloyd's Registry of Shipping.

If the amounts suggested by the supplier differ significantly from the minimum specified, some equalization may be necessary prior to comparing bids.

It is important that a complete list of spares included in the bid be retained. It should be used to audit the spares on site at the time of signing the take-over certificate. Such an audit is necessary to ensure that the spares supplied have not been used up by the supplier during the engine commissioning process.

If a maintenance contract is included, spare parts are usually included along with supervision of operation and maintenance.

6.16 Experience by Supplier on Similar Projects

The mandatory experience requirement in this case relates to the ability of the supplier to manage a complex project. The experience need not have been acquired constructing a diesel plant although this is desirable. Experience gained in the administration of projects of similar or greater value and complexity is acceptable. The supplier must of course list past projects in sufficient detail to facilitate this assessment.
6.17 Financial Stability of Engine Manufacturer

Since the engine is the most costly component of a plant, we need to be assured that the engine manufacturer is financially stable and thus is likely to be in business through the life of the plant. Evidence of financial stability may take the form of past financial reports.

6.18 Service Facilities of Supplier

The supplier must demonstrate the existence of facilities to give prompt and efficient service when needed. These facilities include accessible service shops, adequately trained service personnel and readily available spare parts.

The quality of service offered by the supplier should be further assessed during visits made to reference plants for confirmation of engine operating experience.

6.19 Commercial Terms

The commercial terms offered must be acceptable to the purchaser. The obvious criteria relate to the timing and method of payments. In certain cases there may also be restrictions in the purchaser's country on trade with specific countries. In this case certificates of origin of major components may be required.
6.20 Life of Plant

6.20.1 General

The expected life of a plant affects its life cycle cost, since it determines the period for which the capital investment generates revenue. Theoretically an engine could be kept in service indefinitely by repairing and replacing parts as they become worn. The factors which dictate the retirement of an engine are:

- Cost of repairs.
- Cost of operation (fuel consumption).
- Size of plant relative to system.
- An ability to burn available fuel.

The cost of spare parts for an engine increase if the model is not widely used, since the spares become 'specials' rather than production items. Because of constant development and improvements in technology most engines reach this economic retirement point after twenty to twenty-five years. The other effect of improving technology and general engine development is the improvement in fuel consumption. It may become economic to replace an engine based on fuel savings. Finally, if fuel quality deteriorates as predicted, some engines built today will be unable to cope in the future.

At present, it is usual to assume the expected life of a medium speed four stroke engine to be 20 years, and a two stroke low speed engine to be 25 years. One of the reasons given for this is the claimed 'ruggedness' of the low speed engine and thus its tolerance to abuse. Since this is a contentious issue, it may be safer to base the expected economic life on other factors such as the financial standing of the manufacturer and the number of similar engines sold. If many engines have been sold, even if the manufacturer goes out of business, it would be worth-
while for another manufacturer to produce spare parts. The availability of reasonably priced spare parts is one of the two most important factors in prolonging the economic life of a plant.

6.20.2 Effect of Plant Life on Bid Evaluation

The life of the plant may be applied to the bid evaluation in two ways. If a cost stream is established to determine the life cycle cost of a plant with an expected economic life that is longer than the specified period of the costs stream, the plant is credited with a residual value at the end of the period. If a levelized carrying charge approach is used (see Appendix C), the fixed charge rate is adjusted to reflect the expected life.
SECTION 7

TEST PROCEDURES
7. TEST PROCEDURES AND PERFORMANCE PENALTIES

7.1 Introduction

Before a diesel plant is put into commercial operation it is usual to perform a number of tests to confirm that it has been installed correctly and meets the specified performance criteria. The tests start with checks 1/ on various subsystems as they are completed and culminate in a fuel efficiency test of the entire plant.

One of the most important is the fuel efficiency test since adjusting the bid prices to reflect relative plant efficiency is futile unless we can verify the promised performance. The value of even small efficiency improvements is sufficient to warrant careful testing. We will therefore emphasize the efficiency testing procedure in the remainder of this section.

The following steps should be taken to avoid disputes and delays in commissioning. They are also necessary to enable the test results to be used with confidence in support of the imposition of penalties if performance criteria are not met.

• The type, duration and method of performing all tests must be clearly specified in the specification and contract documents.

1/ The checks include verification of the operation of all the auxiliaries, measuring crankshaft deflections on the engine, engine starting, net power output, load rejection, governor response, overspeed, operation of protection devices, operation of voltage regulator, etc. See for example American Society of Mechanical Engineers, Test Code No. PTC 17-1975.
The standards to which tests must conform should be specified.
The degree of accuracy of the required instrumentation, the accuracy of the test procedure and the procedure for independent calibration of instruments should be specified.
A specific laboratory and test procedure should be designated for determining the calorific value of the fuel used.
Areas of responsibility must be clearly set out. The parties performing and witnessing the tests should be clearly designated.
Procedures for arbitrating disputes must be clearly stated.

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1/ See for example International Standard ISO 3046/1 - Performance testing of Internal Combustion Engines.

2/ The efficiency of the plant is determined by a series of calculations through which individual instrument errors are propagated and compounded. An error bound should be determined to allow a realistic tolerance on results to be specified.

3/ It is desirable for all instruments used in the test to be calibrated and sealed by an independent agency.

4/ When performance tests are done during commissioning, there are inherent conflicts of responsibility. The integrity of the power system, which supplies the load for the test, is the responsibility of the owner, whereas the safety of the plant is the responsibility of the contractor. Some arrangement is usually needed to satisfy their conflicting interests.
7.2 Overall Plant Tests Versus Component Tests

The purchaser is usually interested in maximizing the electrical output of the plant for a given fuel input. Consequently it is desirable to measure these two quantities accurately, on-site, and under the operating conditions envisaged over the life of the plant. The overall input-output approach (see figure 7.1) to measuring efficiency is especially attractive in cases where the plant is supplied on a 'turnkey' basis. Site specific conditions and interfacing arrangements which are difficult to simulate in factory testing are included using this approach.

Figure 7.1: Input-Output Diagram for Overall Efficiency Measurement
On the other hand the results of overall efficiency tests in the field are often inadequate for verifying the attainment of promised performance for the following reasons:

- The instrumentation supplied is not sufficiently accurate to yield meaningful results.
- The plant is not designed to facilitate efficiency testing.
- It is difficult to control environmental conditions.
- The conditions and boundaries of the measurements are poorly specified.

As a result of the high value of efficiency improvements, measures to promote accurate efficiency testing may be justified not only for the commissioning procedure but for long term monitoring of plant performance. These include providing good quality instrumentation, and design features to facilitate testing. 1/

In the event that an accurate (say up to 3% tolerance) overall field test is not possible, a two stage approach is recommended. The major components, engine, generator, and power transformer (if included) may be tested in the factory where test conditions may be carefully controlled. This would be followed by an overall test performed in the field to confirm that the interfacing is acceptable and to estimate auxiliary energy usage. There is even greater need when using this approach to carefully specify the various tests, their limits and objectives.

1/ For example, in a plant with two engines, separate day fuel tanks fitted with load cells may be provided to allow accurate measurement of the fuel input to each engine.
In the following paragraphs we will outline the procedure for major component testing in the factory followed by an overall field test.

7.3 Engine Efficiency Measurements

The efficiency of the engine is related to a thermodynamic process, and thus many variables must be considered. Some of the major factors affecting efficiency are the timing of the engine, adjustment of the injectors and turbocharger performance. These settings change as the engine is used and need periodic adjustment to maintain peak efficiency. When the efficiency of the engine is certified in the factory with a subsequent overall plant test in the field, the factory test and field test have different objectives.

The objective of the factory test is to establish the fuel consumption and lubricating oil consumption to close tolerances under carefully controlled conditions using high quality certified instrumentation. The results of this test may be used as a primary reference, for assigning penalties (liquidated damages) in cases where the performance promised by the supplier is not realized. A second test should be done in the field. The field results should be within a specified tolerance 1/ of the value attained in the factory. The objectives of the field test are to verify the fuel consumption under field conditions and to establish the energy usage of the plant auxiliaries. If the energy usage of the auxiliaries exceed a predetermined limit, a penalty should be applied.

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1/ The tolerance is determined largely by the quality of the instruments used in field testing.
The efficiency test in both factory and field should be done by measuring clean fuel in at $\mathbb{A}$ and electrical energy out at $\mathbb{B}$, see figure 7-2, at the various load points agreed upon (e.g. 20% load, 50% load, 85% load and 100% load). The environmental conditions must of course be measured and the results adjusted to standard conditions.

Figure 7.2: Input-Output Diagram for Engine Efficiency Test
ISO Standard No. 3046 outlines the conditions and procedures for fuel consumption and lubricating oil consumption tests. It provides conversions to relate actual ambient conditions to standard conditions which, briefly, are:

- **Barometric pressure**: 100 kPa
- **Air Temperature**: 300 k (27°C)
- **Relative Humidity**: 60%
- **Charge air coolant temperature**: 300 k (27°C)
- **Lower calorific value for fuel**: 42 000 kJ/Kg

The output is usually measured at the generator with allowance being made for losses through the generator. The measurement of fuel, especially where heavy fuel is used, is probably the most difficult part of the procedure. Many fuel flow meters are unreliable when used with residual fuel. A procedure in which the fuel is weighed is preferable. This is easily done if the plant is designed to facilitate fuel measurement. A suggested method involves the use of a 'day' tank with flexible pipe couplings mounted on load cells. The load cells provide an accurate measurement of weight, and by batching fuel into the tank accurate measurements of fuel consumption are possible. The tank of course should be the final 'clean' tank from which the engine pumps its fuel.

Another important aspect of the initial field test is that it provides a reference data base, against which performance of the plant may be compared through its operating life. This facilitates correct maintenance of the engine.
7.4 Generator and Transformer Testing

The losses associated with the generator and transformer are relatively insensitive to the plant operating conditions and do not change appreciably through the life of the plant. The results of an efficiency test done in the factory and adjusted for local ambient conditions are likely to be representative of their long term performance.

The losses for the generator are measured between D and E and include the power used in the exciter. They consist of electrical losses due to resistance of the windings and mechanical losses due to windage and friction. Losses for

![Diagram of fuel, steam, and power flow](image)

**Figure 7.3:** Input-Output Diagram for Generator and Transformer Efficiency Measurement
the transformer are measured between $E$ and $G$ and include losses due to resistance of the windings as well as magnetizing losses in the core.

Procedures for testing both of these devices are well documented by various standards organizations. The applicable standard should be specified.

### 7.5 Energy Consumption of Auxiliaries

The energy consumption of the auxiliary plant may be measured only in the field. The test should be done over a long enough time span to include items which are used intermittently.

We must carefully specify the conditions under which the tests will be done, and the auxiliary included in the test. For instance, the number of starts on the engine will influence the amount that the starting air compressor runs. It is preferable to include all station equipment in the test including lighting and air conditioning of control room, etc. This may be difficult in cases where the plant is installed in an existing station. Thus, clarity of the specification is important to achieve a meaningful test.

The consumption is measured either by a kilowatt hour meter installed on the main supply to the auxiliaries or by calculating the difference of measurements taken at $E$ and $F$ (see figure 7-4).

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1/ See for example, Test Standards for Efficiency - Power Transformers - International Electrotechnical Commission IEC No. 76-1 and Method for Determining Losses and Efficiency of Rotating Electrical Machinery from Tests IEC No. 34.2.
7.6 Fuel Purification Plant

The prime purpose of the fuel purification plant is to supply fuel free of water and sludge and of the correct viscosity. We therefore should test the viscosity and quality of the fuel supplied to the injectors to establish that the purification plant is performing correctly. This test should be done not only to establish contractual compliance but at regular intervals throughout the useful life of the plant. Suitable permanent instrumentation should therefore be provided.
The other quantity which should be monitored on a long term basis is the weight of sludge and water removed per unit weight of fuel processed. A test should be done at commissioning and at regular intervals thereafter to establish trends. Variations may indicate either that the fuel received is varying in composition, or that the fuel purification plant is malfunctioning.

7.7 Performance Penalties

The inclusion of performance penalties in the contract is intended to discourage suppliers from quoting overly optimistic values for the performance of their plant. The penalties should be based on the cumulative present value of the monetary...
value of the difference in performance. They should also have a punitive aspect, and values of twice or three times the economic cost are usual.

The adjustments for penalties based on a failure to meet expected performance standards should be settled prior to making the final contract payment.
SECTION 8

RELATIONSHIPS BETWEEN OWNER,

CONSULTANT AND CONTRACTOR
8. RELATIONSHIPS BETWEEN OWNER, CONSULTANT AND CONTRACTOR

8.1 Introduction

The relationships between the owner, consultant and contractor(s) are defined by contracts established between the owner and consultant and between the owner and contractor(s). The relationships depend on whether the project is implemented by a number of subcontracts under the control of the consultant or is a 'turnkey' project.

The functions of the owner and contractor(s) are obvious. The consultant is required for three main reasons:

- To supply expertise which the owner cannot justify keeping in-house based on his day to day operation.
- To avail the owner of the benefit of experience gained on similar projects.
- To relieve the overload that would be placed on the owner's staff in implementing the project.

The consultant's main objective is to protect the interests of the owner insofar as those interests are not in conflict with his code of professional ethics.

In the following paragraphs, we will explore the form of contracts and limits of responsibility of the owner, consultant and contractor through the various phases of the project. In addition, we will outline the requirements for insurance coverage to protect the three; owner, consultant and contractor. We will emphasize the 'turnkey' project since this has become predominant in recent years.
8.2 Phases of a Project

There are five identifiable phases of a project. The period leading up to the award of a contract, construction, commissioning, the warranty period and the post warranty period.

Before the award of a contract the consultant is employed by the owner to study the feasibility of the project, prepare functional or detailed specifications, assist with financing negotiations, obtain bids and recommend the award of a contract. The consultant during this phase works as an advisor to the client and maintains close communication with him to properly define his needs. If the project is not to be purchased 'turnkey', then the consultant is more involved in design and takes responsibility for equipment interfacing.

During the construction period the consultant often directs the project on behalf of the owner. His main function is one of auditing. He checks the quality of work and ensures, as far as is practical, that the equipment installed is the same as that listed in the bid document. The consultant may at this time also give some technical assistance to solve unforeseen problems. His other major responsibility is the certification of progress payments to the contractor(s).

In the commissioning period, the consultant monitors tests and recommends acceptance of the plant based on the results. In some cases adjustments are required to compensate for failure of the plant to perform as promised. The consultant advises the owner on the reasonableness of settlements offered by the contractor.

In a 'turnkey' project, it is of course the responsibility of the contractor to deliver a plant which meets all of the specified performance criteria. The consultant has no
responsibility for this and acts only as the owner's technical representative.

During and after the warranty period, the owner usually deals directly with the contractor. The consultant may be retained to advise the owner on any warranty claims, and to assist in maintaining the engine at optimum performance.

8.3 Forms of Contract

The FIDIC 1/ model form for an agreement between a client and consulting engineer for project management is an excellent document for defining the relationship between the client and consultant through the life of a project. It is particularly useful for a 'turnkey' project where the design input from the consultant is minimal. In cases when the consultant designs the plant or does extensive interfacing of component modules, the form for design and supervision of construction of works 2/ is probably more applicable.

1/ International Model Form of Agreement Between Client and Consulting Engineer and International General Rules of Agreement Between Client and Consulting Engineer for Project Management -

EGRA 1980 PM. Produced and issued by the International Federation of Consulting Engineers - FIDIC.

2/ International Model Form of Agreement Between Client and Consulting Engineer and International General Rules of Agreement Between Client and Consulting Engineer for Design and Supervision of Construction of Works -

IGRA 1979 D & S. Produced and issued by the International Federation of Consulting Engineers - FIDIC.
For the contracts between the owner and contractor the appropriate FIDIC document may also be used. The scope of work is of course based on the specification.

Contracts between the owner and supplier for maintenance of the plant after it is put into commercial service have become more frequent. There are four basic areas to be considered in a maintenance contract:

- Supervision
- Replacement Parts
- Labour
- Insurance

Supervision is straightforward. The contractor agrees to supply personnel to supervise maintenance and in some cases operation of the plant on a monthly or annual basis. The responsibilities of such personnel along with their liability should be clearly defined.

Replacement parts are in two categories - normal wear parts and breakdown parts. It is usually best to include both of these in the contract. If wear parts are included, the intended use of the engine must be defined with provision for adjusting the cost of wear parts if the use changes significantly.

Labour is best supplied by the owner. Importing foreign labour is usually frowned upon and often triggers problems with labour unions etc.

Insurance is covered in the next paragraph where we review insurance requirements for an entire project.
8.4 Insurance Requirements

After the contract is awarded, the contractor needs a series of insurance policies to protect his interests. These include:

- Marine insurance (to cover goods in transit).
- Construction insurance (to cover fire, theft, etc. of goods on site).
- Third part insurance (to cover damage to property or person).
- Commissioning insurance (to cover damage to the plant during commissioning).

The contractor may also carry insurance to cover his liability during the warranty period.

Since most warranty agreements cover only the replacement of parts failed due to faulty material or workmanship, the owner should obtain major breakdown insurance upon taking over the plant. In addition, he requires all risk insurance to cover fire, storms, etc. and comprehensive liability insurance to cover damage to persons or property. The consultant can often advise the owner on the extent of coverage required.

If a maintenance contract is in place, the direct insurance requirement of the owner may be reduced. This depends upon the agreement for maintenance. If the maintenance contract includes all parts, wear and breakdown, then the contractor is likely to be covered by a major breakdown insurance policy. Care must be taken, however, to ensure that the owner is fully protected, and this includes the assignment of the 'deductible' that is usually associated with the breakdown policy.

The consultant normally maintains insurance to cover himself to the extent that he is liable.
SECTION 9

FUTURE DEVELOPMENT
9. FUTURE DEVELOPMENT

There are a number of tools which should be developed to enhance our decision making capability in plant acquisitions. Some of these lie in the areas of computational techniques, planning philosophy and input data. The need for further engine development is also evident.

The major computational requirement is in determining, during bid evaluation, the life cycle cost of plants. At present we use mean values for a number of input parameters and derive a single number which is used for deciding on the least cost plant. Our decision to purchase is therefore based on the mean cost only and is insensitive to assumptions in the input parameters. A more reliable decision could be made if we had an assessment of the risk associated with each alternative. A composite decision would then be made using the expected mean life cycle cost and the risk associated with each alternative 1/. This could in some cases lead to the purchase of a plant with a higher mean cost, but with a higher probability of remaining within the projected life cycle cost than an alternative with a lower mean cost 2/.

The input variables of interest are forced outage rate,


fuel cost and the cost of operating and maintenance. If we represent each of these as a probability distribution, we can take the distribution through the calculation and derive a result which is the distribution of life cycle costs for each alternative. We can then use utility theory as outlined in reference 2 to make a decision.

The requirement for a distribution of the input parameter value implies that we need to collect more data. This of course would lead to greater confidence in the results.

A major issue which relates back to the planning stage is the determination of the optimum effective capacity required by the system. All of our bid evaluation efforts presume that the required effective capacity has been already determined.

In determining the effective capacity required, we often use a year by year expansion and add various alternative units to satisfy the reliability criteria prior to doing production costing. This approach does not adequately determine the optimum size of unit or block of effective capacity required. A horizon year approach is probably more relevant. The two main issues associated with the size of unit are those related to the effect of multiple units on reliability, and the economy of scale associated with larger units.

Another issue of which planners should be aware is the extent to which engine failures are fuel related. A diesel generating plant with a forced outage rate of 18% may be improved to as low as 5% by changing from residual to distillate fuel. In some cases the required effective capacity may be obtained by making this change, of course with the attendant higher fuel cost. However such a change should be considered as a possible alternative to adding new
plant. Further effort is required in analyzing failures and assessing the extent to which they are fuel related. A classification of the quality of fuels available in various parts of the world would also be of benefit 1/.

1/ A programme has been started by Det Norske Veritas which supplies such a listing to member shipping companies. The information would be useful to utilities. For more information see Det Norske Veritas Testing Programme, Paper Series No. 82 P048 July 1982.
APPENDIX A

CALCULATION OF EFFECTIVE CAPACITY
APPENDIX A: CALCULATION OF EFFECTIVE CAPACITY

A.1 Factors Important to the Calculation of Effective Capacity

The effective capacity of a new unit added to a generating system is a function of both the characteristics of the existing system and of the new unit. The important characteristics of the added unit include its site peak rating and its expected forced outage rate (FOR). The expected FOR is based on forced outage statistics for units of size and type similar to the new unit which are subject to conditions of service and fuel quality similar to those anticipated for the new unit.

The ability of the existing system to accommodate increases in peak demand is significant in calculating the effective capacities of new additions. Garver uses a single parameter, 'm', to measure this ability. He defines m as the amount (in megawatts) by which the peak demand must increase, to cause the system risk level to increase by a factor of e, the base of the natural logarithm. It therefore has the units of megawatts. If the plot of loss of load expectation (LOLE) vs. peak demand is graphed on semilogarithmic paper, the value of m can be calculated directly as the slope of the curve. It is taken at the target LOLE level since effective capacities are measured at this point. The value of m can also be approximated as the summation of the products of the peak capacity and FOR (in per unit) for each of the units in the existing system. The importance of this approximation will be shown later.

The following illustration shows how the value of m can be determined from the Risk vs. Load curve:

---

**Figure A-1: Graphical Approximation of 'm'**

The risk level (in days per year), $R_2$ is $e$ times greater than $R_1$, the target level.

Consequently,  

$$m = L_2 - L_1 \quad \text{(1)}$$

Because of difficulty in working accurately with the logarithmic scale, any integral value of risk, $R_3$ near the target level, $R_1$ can be chosen and used in the following equation:

$$m = \frac{L_3 - L_1}{\ln \frac{R_3}{R_1}} \quad \text{(2)}$$

Equation (1) is just a special case of equation (2) in which the denominator has a value of one.
A.2 An Approximate Calculation Technique

The approximation developed by Garver for the effective capacity of an added generating unit is given in the following equation:

\[ c^* = c - m \times \ln \left\{ (1-r) + r\frac{c}{m} \right\} \] ........................ (3)

where
- \( c^* \) is the effective capacity (MW) of the new unit
- \( c \) is the site peak rating (MW) of the new unit
- \( m \) is the characteristic value for the existing system
- \( r \) is the expected FOR (in per unit) of the new unit

This relationship was developed on the basis of data from medium and large sized electric utilities. Consequently, it is most accurate in application to utilities of those sizes. Garver gives a hypothetical example of a system with a peak rating of 4600 MW to which is added a 600 MW unit with a FOR of 0.05. The approximation yields a value of effective capacity of 341 MW which is within 6% of the 362 MW value obtained with digital computing techniques simulating system operation.

Direct application of equation (3) to plant additions for smaller utilities in developing countries results in errors which may range up to 30%. An analysis of the problem reveals that the value of the term \( r\frac{c}{m} \) is subject to a large variation. The physical significance of the variation is evident when the circumstances surrounding the development of the approximation are borne in mind. A contrast between these circumstances and those surrounding the application to developing countries is summarized by the following points:

1) The rate of growth of demand is far higher and more erratic for utilities in developing countries than it is for Garver's model utilities. Consequently, individual plant additions there generally constitute a much larger fraction of the existing system capacity than in
the study cases. Thus both the ratio $c/m$ and the expression $e^{c/m}$ are larger.

2) Because diesel power plant is installed more frequently in developing countries than thermal plant, due to practical size limitations, forced outage rates, $r$, of new plant are generally greater, averaging as high as 18% for medium speed four stroke units burning residual fuel.

A.3 A Modified Approximation

In cases where direct application of equation (3) would result in large errors, a modified version, equation (4), is proposed.

\[
c^* = c - m \times \ln \left\{ \left( 1 - r \right) + kr e^{c/m} \right\} \quad \text{(4)}
\]

The modifying constant, $k$, has the following form:

\[
k = \frac{1}{B_1 x} \quad \text{(5)}
\]

where: $B_1$ is a constant and

\[
x = (r B_2) \left( \frac{C}{C_1} \right)^{B_3} \quad \text{(6)}
\]

where: $B_2$ and $B_3$ are constants

$r$ is the forced outage rate of the new unit

$c$ is the site peak rating (MW) of the new unit

$C_1$ is the installed peaking capacity (MW) of the existing system

The intent of the multiplier, $k$, is to moderate the second bracketed term in equation (4). Its characteristics are such that for "small" values of $r$ and the ratio $c/C_1$, $k$ tends to unity, while for "large" values of these parameters, $k$ tends to zero. Consequently, it is possible to achieve greater accuracy in comparing diverse plant types for application to a given system despite the wide variations in size and forced outage rate that characterize them.
The inaccuracy discussed thus far may be termed "relative" inaccuracy. It results from a shortcoming in the modelling technique that introduces a significant degree of bias when comparing different types of plant. The modification proposed in equation (4) attempts to minimize this bias.

A.4 Absolute Error

Absolute error is introduced by several factors which are independent of the plant being considered for addition. Because of the discrete nature of the blocks of existing generating capacity, and because of the simplification necessary to model the system load, the actual relationship between LOLE and system peak load is discontinuous. The absolute error results from the convention of approximating this discontinuous relationship by a smooth and continuous curve. The degree of discontinuity depends largely on the size of the existing units relative to the total capacity of the utility. In this respect, the modelling technique has limitations even for large utilities.

It is important to note, however, that since the absolute error affects consideration of each alternative equally, its elimination is not essential to unbiased selection of a generating unit. Consequently, no attempt is made to apply a correction.

A.5 Evaluation of the Constants

Appropriate selection of the constants B1, B2 and B3 in equation (4) is vital to the accuracy of the approximation since each combination of an existing utility and the proposed additions to it, is unique. Through an iterative approach, these constants can be determined to the desired accuracy if the following information is available:
the value of m for the existing system;
- values for the effective capacity of various plant additions to the existing system.

The value of m is necessary for insertion into equation (4). It is available from the computer output of a generation planning study. Actual values of effective capacity are obtained from the same source and are of value only if the plant size and type they represent is being given serious consideration as an alternative. They are used as the standards against which the approximate values of effective capacity are tested during the iterative process.

To give equal consideration to each plant size and type, the effective capacity of each proposed addition is calculated for each combination of values considered for B1, B2 and B3. These approximate values of effective capacity are then subtracted from their respective standard values and an absolute value taken to obtain a set of deviances. Appropriate selection of the constants results in the lowest average value of deviance for the given system and set of alternative additions.

A.6 Application of the Approximation

The procedure described in the previous section yields a set of constants that permit a high degree of accuracy in the approximation of effective capacities for a given application. However, the lack of input information (m, etc.) sometimes makes it impossible to evaluate the constants for equation (4). It is still possible to use the method under these circumstances, m can either be read directly from the printout or calculated as shown in Figure A-1.

2/ effective capacities are determined as shown in Figure 6-1.
but two approximations are necessary which further limit its accuracy. The first, an estimate for the value of \( m \), was mentioned briefly in subsection A.1 and is summarized by the following equation:

\[
m = \sum_{i=1}^{N} c_i r_i \]

where:

- \( m \) is the characteristic value for the existing system
- \( c_i \) and \( r_i \) are the peak capacity and forced outage rate for the \( i^{th} \) unit in the system
- \( N \) is the total number of existing units in the system

The second approximation involves using the following values for the constants in equation (4):

- \( B_1 = 10.0 \)
- \( B_2 = 0.11 \)
- \( B_3 = 1.80 \)

These values were derived using the method outlined in subsection A.5. Data from three existing utilities was used as the basis for the calculation. The utilities are described briefly in table A-2. The plant alternatives considered ranged in size from 1.2 to 12 MW while the forced outage rate, \( r \), varied from 0.04 to 0.18.

<table>
<thead>
<tr>
<th>Utility</th>
<th>( C_1 ) (MW)</th>
<th>( m ) (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>95</td>
<td>6.2</td>
</tr>
<tr>
<td>#2</td>
<td>17</td>
<td>1.2</td>
</tr>
<tr>
<td>#3</td>
<td>7</td>
<td>1.0</td>
</tr>
</tbody>
</table>

On the basis of the utility and plant input data used to derive the above constant values, they should produce reasonable accuracy in application to small utilities in developing countries.
A.7 Multiple Additions

The modified form of Garver's approximation (equation (4)) is of considerable value in comparing the effective capacities of dissimilar plant types at various stages of the generation expansion program. A particularly significant attribute is the ability to accurately model a number of simultaneous or successive plant additions. This is important during generation planning when it is desired to evaluate the status of the system at each stage of a proposed expansion scheme. It is even more important at the tender evaluation stage since for a given plant addition, each tender may propose the addition of a different combination of units. The only way to accurately compare the tenders is on the basis of the total effective capacity added.

Because each unit of a generating system operates independently, an accurate assessment of a multi-unit addition requires the effective capacity of each unit to be calculated separately. In each calculation, the capacity of the existing system, \( C_l \), and the system characteristic value, \( m \), are determined as follows:

\[
C_{l_N} = C_{l_0} + \sum_{i=1}^{N-1} C_{i-1} \hspace{1cm} (8)
\]

\[
m_N = m_0 + \sum_{i=1}^{N-1} C_{i-1}r_{i-1} \hspace{1cm} (9)
\]

where:

- \( C_{l_N} \) and \( m_N \) are the values of system capacity and the system characteristic to be used in the calculation of the effective capacity for the \( N^{th} \) unit added
- \( C_{l_0} \) and \( m_0 \) are the original values of system capacity and the system characteristic
- \( C_i \) and \( r_i \) are the values of capacity and forced outage rate for the \( i^{th} \) unit added
The total effective capacity added is simply the summation of the individual effective capacities

\[ C^{*\text{TOT}} = \sum_{i=1}^{N} C^{*i} \] (10)

where

- \( C^{*\text{TOT}} \) is the combined effective capacity of \( N \) successive or simultaneous additions
- \( C^{*i} \) is the effective capacity of the \( i^{th} \) unit added

See figure A-2 for an algorithm to calculate the effective capacities of plant additions to any system.
Want to Compare Effective Capacities of Potential Plant Additions

Accurate values of m and effective capacities for sample cases are available from a recent planning study?

YES

Use iterative approach to calculate B1, B2 & B3

Calculate Effective Capacity using:

\[ C^e = e \cdot \min((1-r) + \kappa r^{a/m}) \]

Return m and C1 to Original Values

Another Unit Addition in This Sequence?

YES

Update Values of m and System Capacity, C1

NO

Test Another Sequence?

YES

NO

Analyze Results

Figure A-2: Flow Chart for Comparing Effective Capacities
APPENDIX B

OUTLINE OF

DIESEL PLANT MAINTENANCE CONTRACT
APPENDIX B: OUTLINE OF DIESEL PLANT MAINTENANCE CONTRACT

1. Definition of Parties Involved.
2. Duration of Agreement.
3. Definition of Plant Service Requirements.
4. Scope of Equipment Covered Under the Agreement.
5. Definition of Responsibility.
6. Definition of Authority.
7. Limitation of Contractor’s Liability.
8. Major Breakdown Insurance.

B.1 Definition of Parties Involved

This section should define (using the proper legal titles) those parties bound by the contract or by any part of it.

B.2 Duration of Agreement

The starting date of the agreement should be specified either as a calendar date, or as date on which a specified event occurs. The completion date should be specified either as a calendar date, or as the last date of a period of specified length that begins on the starting date.

B.3 Definition of Plant Service Requirements

The intended service of the plant (baseload, peaking,
etc.) should be specified as well as the estimated annual generation and the estimated annual number of service hours under the following conditions:

<table>
<thead>
<tr>
<th>Load</th>
<th>% MCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>50% MCR</td>
<td>75% MCR</td>
</tr>
<tr>
<td>100% MCR</td>
<td>110% MCR</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
</tr>
</tbody>
</table>

The minimum requirement for plant availability should be specified in this section.

B.4 Scope of Equipment Covered Under the Agreement

This section should define exactly which pieces of equipment are included under the terms of the agreement. Typically, this is limited to the engine and engine-mounted auxiliaries.

B.5 Definition of Responsibility

The agreement should state the extent to which each of the contracting parties is responsible for the following items:

- Maintenance supervision
- Maintenance labour
- Supply and control of spare parts for - initial stock - wear and tear replacement
- Government liason and compliance with government requirements
- Establishment of standards for maintenance (procedures and schedules)
• Adherence to standards
• System monitoring and report preparation (specifics on data, format and frequency)
• Supply and maintenance of tools, oil filters, etc.
• Specifics and timing of inter-organization communication

B.6 Definition of Authority

This section should intensify an individual within one of the contracting organizations who has the authority to shut down the engine for preventative maintenance if he thinks that failure to do so will result in a catastrophic breakdown. It should also delineate the authority of each organization to assign and remove maintenance labour and supervisory personnel.

B.7 Limitation of Contractor's Liability

The nature and cause of breakdown incidents for which the contractor does not bear cost responsibility should be outlined.

B.8 Major Breakdown Insurance

For protection of the owner, major breakdown insurance must be carried to cover the cost of major failures not otherwise provided for. Three alternative arrangements are detailed below:

B.8.1 Owner Carries Insurance/Pays Premium/Pays Deductibles

Under this arrangement, there is limited incentive for the contractor to assist in avoiding major breakdowns, par-
ticularly if the maintenance contract limits his liability to repair of the initial failure. Since the repair of secondary damage often costs significantly more than repair of the initial failure, the owner may incur unnecessary costs in insurance claim deductibles and increased premiums.

B.8.2 Contractor Carries Insurance/Pays Premium/Pays Deductibles

Since under this alternative, the contractor is responsible to the owner for all breakdowns (contract wording is very important), there is great incentive for him to minimize their occurrence. Furthermore, the owner is protected during the maintenance agreement from variations in the cost of insurance. One drawback of this arrangement is that the owner must, at the beginning of the contract, pay the insurance costs as a lump sum incremented by the Contractor's markup.

B.8.3 Owner Carries Insurance/Pays Premium/Contractor Pays Deductibles

The owner is fully protected under this scheme with payment of deductibles serving as incentive for the contractor to co-operate fully. It differs from Alternative #2 in that the owner trades off initial cost for the risk of higher premiums.

B.8.4 A Note on Additional Protection

The most reliable way of protecting the owner's interests in the maintenance agreement is to require the posting of a performance bond. This insures against occurrences which are outside of the contractor's control such as bankruptcy of the
contracting firm. A performance bond should be required no matter what arrangement is made for major breakdown insurance.

**B.9 Price and Conditions of Payment**

Details of the financial arrangement should be outlined in this section.

**B.10 Procedure for Contract Modification**

The general procedure for implementing changes which are mutually agreeable to the contracting parties should be outlined in this section. Details should also be included for a procedure to modify the contract price to reflect discrepancies between the actual and estimated (subsection B.3) values of unit service hours and load factor.

**B.11 Procedure for Settlement of Disputes**

A procedure should be detailed to permit either party to enforce the terms of the agreement in the event that the second party is not meeting these terms. The law under which arbitration and litigation will take place should also be specified here.

**B.12 Conditions for Termination of Contract**

The conditions under which the agreement may be prematurely terminated by either party should be included here along with the procedure for calculation of the financial settlement.
B.13 Glossary and Summary of Applicable Standards

The agreement should include a glossary to define any special terms used in the conditions of contract. Also included should be a summary of the standards used in the definitions, performance tests and all other matters relating to the agreement.
APPENDIX C

COMPARISON OF

PROJECTED LIFE CYCLE COSTS
APPENDIX C: COMPARISON OF PROJECTED LIFE CYCLE COSTS

It is important that bid evaluations be based on total life cycle cost, rather than capital cost, if the purchaser is to achieve the maximum benefit from a plant investment. Two standard evaluation methods are presented below with the aid of an example comparison.

C.1 Cumulative Present Worth

In this method, the present worth of costs incurred throughout the life of a unit are summed for comparison with those of other alternatives. The example shows three contributing cost streams. They are: a) Capital; b) Adjustment; c) O & M (summation of all annual expenses).

C.1.1 Capital

The capital cost used is the value quoted by the supplier.

C.1.2 Adjustment

The adjustment is a lump sum added to or subtracted from the capital cost of each alternative to ensure that all bids conform to the pre-determined requirement for quality of service. It accounts for small variations in effective capacity as well as the reliability of auxiliary systems (equipment redundancy, spares, etc.).
C.1.3 Annual Expenses

This category accounts for all annual expenses associated with owning, operating and maintaining each alternative. The example uses relative values, each referenced to the pre-determined standard value. This simplified the calculation without affecting the relative ranking of the alternatives considered. Table C-1 summarizes the comparison.

C.2 Levelized Annual Cost

This method compares plant alternatives on the basis of the combined annual capital and operations cost of each plant, levelized over its economic life. The two alternatives used in this example have different economic life spans. This difference is reflected in the fixed charge rates for the capital portion of the levelized annual cost.

The Levelized Annual Operating Costs, Adjusted Capital Costs and Economic Lives used in Table C-2 are the same as in the previous example.

It can be seen that with either comparison method, Alternative B is slightly more attractive than Alternative A, despite its shorter economic life.
Table C-1: Comparison of Projected Life Cycle Costs for Two Plant Alternatives

<table>
<thead>
<tr>
<th>YEAR</th>
<th>CAPITAL (1982 $x 10^3)</th>
<th>ADJUSTMENT</th>
<th>O &amp; M</th>
<th>ANNUAL</th>
<th>CUMULATIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>1982</td>
<td>6000</td>
<td>5200</td>
<td>200</td>
<td>300</td>
<td>310</td>
</tr>
<tr>
<td>1983</td>
<td>310</td>
<td>350</td>
<td>247</td>
<td>279</td>
<td>6724</td>
</tr>
<tr>
<td>1984</td>
<td>310</td>
<td>350</td>
<td>221</td>
<td>249</td>
<td>6945</td>
</tr>
<tr>
<td>1985</td>
<td>310</td>
<td>350</td>
<td>197</td>
<td>222</td>
<td>7142</td>
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<tr>
<td>1986</td>
<td>310</td>
<td>350</td>
<td>176</td>
<td>199</td>
<td>7318</td>
</tr>
<tr>
<td>1987</td>
<td>310</td>
<td>350</td>
<td>157</td>
<td>177</td>
<td>7475</td>
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<tr>
<td>1988</td>
<td>310</td>
<td>350</td>
<td>140</td>
<td>158</td>
<td>7615</td>
</tr>
<tr>
<td>1989</td>
<td>310</td>
<td>350</td>
<td>125</td>
<td>141</td>
<td>7740</td>
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<tr>
<td>1990</td>
<td>310</td>
<td>350</td>
<td>112</td>
<td>126</td>
<td>7852</td>
</tr>
<tr>
<td>1991</td>
<td>310</td>
<td>350</td>
<td>100</td>
<td>113</td>
<td>7952</td>
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<tr>
<td>1992</td>
<td>310</td>
<td>350</td>
<td>99</td>
<td>101</td>
<td>8041</td>
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<tr>
<td>1993</td>
<td>310</td>
<td>350</td>
<td>89</td>
<td>90</td>
<td>8121</td>
</tr>
<tr>
<td>1994</td>
<td>310</td>
<td>350</td>
<td>71</td>
<td>80</td>
<td>8192</td>
</tr>
<tr>
<td>1995</td>
<td>310</td>
<td>350</td>
<td>63</td>
<td>72</td>
<td>8255</td>
</tr>
<tr>
<td>1996</td>
<td>310</td>
<td>350</td>
<td>57</td>
<td>64</td>
<td>8312</td>
</tr>
<tr>
<td>1997</td>
<td>310</td>
<td>350</td>
<td>51</td>
<td>57</td>
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<tr>
<td>1998</td>
<td>310</td>
<td>350</td>
<td>45</td>
<td>51</td>
<td>8408</td>
</tr>
<tr>
<td>1999</td>
<td>310</td>
<td>350</td>
<td>40</td>
<td>46</td>
<td>8448</td>
</tr>
<tr>
<td>2000</td>
<td>310</td>
<td>350</td>
<td>36</td>
<td>41</td>
<td>8484</td>
</tr>
<tr>
<td>2001</td>
<td>310</td>
<td>350</td>
<td>32</td>
<td>36</td>
<td>8516</td>
</tr>
</tbody>
</table>

Notes:
1) The expected economic service lives of alternatives A and B are 25 and 20 years respectively.
2) The present worth values are referenced to the beginning of 1982 using a discount rate of 12%.
3) The residual value of Alternative A is the present worth of the non-depreciated portion of the capital cost after 20 years of its 25 year life.
Table C-2: Plant Comparison Using Levelized Annual Cost

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Economic Life (Yrs.)</th>
<th>Fixed Charge Rate (%)</th>
<th>Levelized Annual Capital Cost(^1) ((1982$))</th>
<th>Levelized Annual Operating Cost(^3) ((1982$))</th>
<th>Levelized Annual Total Cost(^4) ((1982$))</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>25</td>
<td>16</td>
<td>992</td>
<td>310</td>
<td>1,302</td>
</tr>
<tr>
<td>B</td>
<td>20</td>
<td>17</td>
<td>935</td>
<td>350</td>
<td>1,285</td>
</tr>
</tbody>
</table>

1) Because this is an economic analysis, taxes are ignored. Therefore, the fixed charge rate = Cost of Capital plus rate of depreciation.

2) Levelized Annual Capital Cost = fixed charge rate \times \text{Installed cost}.

3) Levelized Annual Operating Cost includes all annual expenses such as fuel, operation and maintenance.

4) All costs \times 10^3.
APPENDIX D

EVALUATION OF

ALTERNATIVE FINANCIAL OFFERS
APPENDIX D: EVALUATION OF ALTERNATIVE FINANCIAL OFFERS

D.1 Overall Scheme

In order to evaluate the alternative financial schemes offered by the various suppliers, it is necessary to separate financial costs from capital costs. Once calculated, the financing costs may be recombined with the capital cost after the economic evaluation is completed.

The cost of financing is determined by establishing a cost stream of financing components. The present value of this cost stream is then determined.

Two additional factors possibly affecting the corporate financial structure must then be considered; these are the relative magnitude of the capital expenditure and the effect on corporate income taxes of the capital and interest payments. If these items are considered to have a significant effect, then the financial cost stream data must be entered into a corporate model forecast to facilitate a more thorough analysis.

D.2 Elements of Financial Schemes

D.2.1 Supplier Credit

The supplier credit is generally expressed as either equal payment or equal principal repayment. The cost streams of payments are determined by month for both principal and interest. In addition, the disbursement schedule of these funds is obtained from the supplier based on his expected construction schedule. Lump sum payments are entered into the appropriate month in the overall cost stream.
Balloon payments if quoted as part of the financing scheme are also taken into account.

D.2.2 Buyer Credits

For that portion of the capital not financed by the supplier, the buyer has the option of arranging his own financing or alternatively the supplier may attempt to negotiate a loan for the buyer. As with the supplier credit, the actual principal and interest paid are entered in the appropriate months.

D.2.3 Loan and Management Charges

The fees associated with the management and establishment of the buyer and supplier credits must be taken into account in the cost stream. Three of the more common forms of these fees are:

- Fees expressed as a percent of undisbursed principal. The expected disbursement schedule is established based on supplier's information. The undisbursed principal is calculated for each month. The percentage is applied to the undisbursed figure usually on a monthly basis with the actual payments made according to the condition of the agreement.

- Fees expressed as a fixed amount. In this case the fees are expressed as either a fixed dollar amount or as a final percentage of contract price. The payments are made in specifically stated periods or over a range of periods.

- Percent of Balance of Principal Outstanding Based on the repayment of principal a percentage is applied to the balance of unpaid principal the frequency of which is specified in the conditions of the loan.
D.2.4 Interest During Construction

Interest During Construction is related to the disbursement schedule and even if paid in one lump sum at the conclusion of construction, is generally compounded over the construction period.

D.3 Financial Scheme Cash Flow

D.3.1 The cash flow of the financial scheme for each month is determined by adding the elements of section D.2.

D.3.2 While it is possible to prepare the cash flow manually it is more expedient to use a computer. The repetitive nature of the calculation lends itself favourable to computer programming. The ideal program is one that can assign to the appropriate periods, the various payments of principal and interest during construction. Either the program must be general enough to handle the various types of financing offered, or the buyer must, in his specification, restrict the types of financing to be considered.

D.3.3 Having determined the cash flow by month, the results may be used in either of two ways:

- As part of the utility corporate model forecast.
- Bid comparison.
D.4 Bid Comparison

D.4.1 By applying appropriate discount factors to the cash flow of financial payments, the present value of the capital cost and financing scheme may be determined.

D.4.2 Subtracting the capital cost from this amount leaves a present value of the financing scheme. This amount may then be considered as part of the overall cost of the plant.

D.4.3 Alternatively the present value of the capital and financing cost could be expressed as a levelized annual cost by dividing the total present value by the present worth of an annuity factor for a predetermined number of periods and interest rate.

D.5 Corporate Model Forecast

If the magnitude of the investment is sufficiently large to significantly affect the overall corporate cash flow, a corporate model forecast is used to determine the effect of various financing schemes. The model will take into account such items as tax implications, including investment tax credit, cash flows, rate base and revenue requirements. Once again, this analysis should be computerized in order to facilitate sensitivity analysis.

The corporate model forecast will produce estimates of income statements, cast reports and balance sheets for future years for each of the financial schemes offered. It will show the effect of the scheme on short term required capital investment and on earnings.
APPENDIX E

DEFINITION OF TERMS
APPENDIX E: DEFINITION OF TERMS

Effective Capacity - the amount by which a new generating unit added to an existing system increases the peak load carrying capability of that system at its target reliability level.

Service Hours (SH) - the total number of hours in a specified period (usually a year) during which a generating unit is synchronized with the grid and generating power.

Forced Outage Hours (FOH) - the total number of hours in a specified period (usually a year) during which a generating unit is unavailable for generation because of forced outages.

Forced Outage Rate (FOR) - the probability of the existence of a forced outage at a random point in time. This probability can with reasonable accuracy be approximated for base load units with the following expression:

\[
\text{FOR} = \frac{\text{FOH}}{\text{FOH} + \text{SH}}
\]

The components of this equation are defined above. This approximation must be modified to achieve acceptable accuracy when dealing with units in intermediate or peaking service.

Loss of Load Expectation (LOLE) - the estimated time (usually expressed as days per year) during which the generating capacity in a given system will be inadequate to supply the projected demand.

Loss of Load Probability (LOLP) - the estimated probability that within a given time period the generating capacity in a given system will be inadequate to supply the projected demand.
System Characteristic Constant (m) - the amount (in megawatts) by which the peak demand of a given system at its target reliability level must change to cause the system risk level to change by a factor of e, the base of the natural logarithm.

Maximum Continuous Rating (MCR) - the maximum load that an engine can carry on a continuous basis under site conditions.

Peaking Capacity - the maximum short term load (generally for 1 hour in 12) that can be carried by an engine under site conditions. It is normally 110% of MCR.

Planned Outage Hours (POH) - the total number of hours in a specified period during which a unit is unavailable for generation because of planned maintenance.

Planned Outage Rate (POR) - the amount of time, stated as a percentage, during which a unit is unavailable for power generation because of planned maintenance.
APPENDIX F

TERMS OF REFERENCE
ATTN: HOUGHTON

REFERENCE OUR MAY 28 TELEPHONE DISCUSSION AS FOLLOWUP YOUR DIESSEL PLANT PERFORMANCE STUDY COMPLETED 1980 FOR WORLD BANK. PLEASE PROVIDE LUMP SUM PROPOSAL FOR PREPARING GUIDELINE SPECIFICATIONS AND BID EVALUATION PROCEDURE APPLICABLE TO BID INVITATIONS PERMITTING BOTH MEDIUM AND LOW SPEED DIESELS. OBJECTIVE IS TO PROVIDE BANKE ENGINEERS AND/OR CONSULTANTS GUIDANCE ON DESIRABLE SPECIFICATION COVERAGE INCLUDING DESCRIPTION; TECHNICAL CHARACTERISTICS; RANGE OF ACCEPTABLE VALUES; TYPICAL GUARANTEE EXPECTATIONS; MAINTENANCE CONTRACT POSSIBILITIES; ALLOCATION OF RELATIVE OWNER/SUPPLIER/CONSULTANT RESPONSIBILITIES DURING INSTALLATION; TEST PROCEDURES; OPERATING COSTS; TRAINING ARRANGEMENTS AND OTHER FACTORS AFFECTING ECONOMIC COMPARISON OF BIDS FOR MEDIUM AND LOW SPEED DIESELS TOGETHER WITH RECOMMENDED CRITERIA FOR QUANTIFYING THESE CHARACTERISTICS AND EVALUATION FORMULA/PROCEDURE BASED ON OBJECTIVE OF MINIMUM SYSTEM ELECTRICITY COST. GUIDELINES WOULD SERVE AS MODEL OR CHECKLIST ON BANK PROJECTS WHERE BORROWERS WISH TO CONSIDER BOTH DIESSEL TYPES AND EQUITABLE BID COMPARISON IS DIFFICULT BECAUSE OF CAPITAL OPERATING COST TRADE-OFF. DETAILED TERMS OF REFERENCE NOT PRACTICAL GIVEN SPECIALIZED SUBJECT THEREFORE SUGGEST YOU OUTLINE PROPOSED PLAN. WE ENVISAGE IMPLEMENTATION WOULD INVOLVE WASHINGTON TRIPS FOR (1) STUDY DISCUSSION; (2) REVIEW OF EXISTING DIESSEL SPECIFICATIONS AND BID EVALUATION ON TYPICAL PAST BANK DIESSEL PROJECTS; (3) DISCUSSION OF DRAFT REPORT. NO FIELD TRIPS FOR UPDATING DIESSEL OPERATIONAL DATA ANTICIPATED. REPORT WOULD CONSIST OF STATEMENT OF ISSUES AND CRITERIA WITH SUPPORTING CALCULATIONS WHERE NECESSARY PLUS OUTLINE SPECIFICATIONS AND SUGGESTED DRAFT PARAGRAPHS COVERING EVALUATION CRITERIA AND PROCEDURES. PRINTED REPORTS TO NUMBER TEN DRAFT AND FIFTY FINAL FOR CIP ACCOUNT. STUDY TO COMMENCE IMMEDIATELY AFTER PROPOSAL ACCEPTANCE; PAYMENT BASED ON 40% ON ACCEPTANCE; 40% ON RECEIPT DRAFT REPORT; 20% ON ACCEPTANCE OF FINAL REPORT. APPRECIATE DETAILED PROPOSAL ASAP INCLUDING INTENDED STAFF AND EXPECTED HANDAYS. REGARDS MOORE WORLD BANK

CIPOWER MTL

WORLD BANK WSH
APPENDIX G

EXAMPLE OF

TYPICAL BID EVALUATION
APPENDIX G: EXAMPLE OF TYPICAL BID EVALUATION

G.1 Introduction

The following is a simplified example which shows the major steps in a bid evaluation. Although we have attempted to use realistic values, they should not be assumed to be applicable to a specific project. A prospective purchaser should use values for the various input parameters which are relevant to his particular situation.

In the evaluation below, the low speed diesel plant would have been chosen as the least cost option. Table G-1 summarizes the various steps in the evaluation process. We assume for the purposes of this example that both bids being considered have satisfied the mandatory requirements (items 1 to 8 in table G-1).

G.2 Information Given to Suppliers

Along with the standard information about the existing plant, scope of supply and local conditions, etc. the following would have been given to the prospective suppliers:

- Installed capacity of existing system 94 MW
- Load carrying capability of existing system 44 MW
- 'm' for existing system 6.2 MW
- Effective capacity required 20 ± 1 MW
- Maximum number of units 5
- Forced outage rate for low speed two stroke engine 0.05 per unit
- Forced outage rate for medium speed four stroke engine 0.18 per unit
### Table G-1: Sample Evaluation of Two Bids

<table>
<thead>
<tr>
<th>NUMBER</th>
<th>EVALUATING ITEM</th>
<th>DESCRIPTION</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Engine operating experience.</td>
<td>OK</td>
<td>OK</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Effective capacity requirement.</td>
<td>OK</td>
<td>OK</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Basic warranty.</td>
<td>OK</td>
<td>OK</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Minimum spare parts requirement.</td>
<td>OK</td>
<td>OK</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Experience by supplier on similar projects.</td>
<td>OK</td>
<td>OK</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Financial stability of engine manufacturer.</td>
<td>OK</td>
<td>OK</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Service facilities of supplier.</td>
<td>OK</td>
<td>OK</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Commercial terms.</td>
<td>OK</td>
<td>OK</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Tendered price of plant.</td>
<td>26160000</td>
<td>17920000</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Equipment equalization.</td>
<td>100000</td>
<td>----</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Base price (adjusted for equipment equalization).</td>
<td>26260000</td>
<td>17920000</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Price after adjustment for life expectancy.</td>
<td>25650206</td>
<td>17920000</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Specific fuel consumption.</td>
<td>1317162</td>
<td>2356074</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Generator losses.</td>
<td>----</td>
<td>----</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Main power transformer losses.</td>
<td>----</td>
<td>----</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Auxiliary power consumption.</td>
<td>----</td>
<td>----</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Lubricating oil consumption.</td>
<td>553803</td>
<td>1600999</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Maintenance cost.</td>
<td>(2511579)</td>
<td>6089932</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Mechanical design features.</td>
<td>(787800)</td>
<td>----</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Engines similar to existing engines in plant.</td>
<td>(358400)</td>
<td>----</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Arrangements for training of staff.</td>
<td>----</td>
<td>----</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Engine manufacturer as prime contractor.</td>
<td>----</td>
<td>(89600)</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Supplier's past performance.</td>
<td>(105040)</td>
<td>(107520)</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Miscellaneous</td>
<td>----</td>
<td>----</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TOTAL EVALUATED COST</td>
<td>24116752</td>
<td>27410585</td>
<td></td>
</tr>
</tbody>
</table>
• Life of plant for low speed two stroke engine 25 years
• Life of plant for medium speed four stroke engine 20 years
• Discount rate 12%
• Method of evaluating various features of the plant and the amount by which each evaluating item will affect the base price. The evaluation methodology is outlined in Section 6. For this example, the evaluating items affect the base price as follows:
  - Mechanical design features 3% of base price
  - Engines similar to those existing 2% of base price
  - Arrangements for training of staff 0.5% of base price
  - Engine manufacturer as prime contractor 0.5% of base price
  - Supplier's past performance 1% of base price
  - Miscellaneous 0.5% of base price

G.3 Bid A

Let us assume that supplier 'A' is providing low speed two stroke units. He would have performed the calculation shown in section 6.2 page 6-12 and would offer the following:

- Number of units 2
- Maximum continuous rating 10.9 MW
- Short time peaking rating 12.0 MW
- Cost per kilowatt (based on MCR) $1200.00

G.4 Bid B

Supplier 'B' who offers medium speed diesels would have performed the calculations shown on page 6-15 and may have selected
the following from his inventory:

- Number of units 4
- Maximum continuous rating 6.4 MW
- Short time peaking rating 7.0 MW
- Cost per kilowatt (based on MCR) $700.00

G.5 Base Price

We first obtain the tendered prices from the suppliers' quotations. In this case we have:

- For Bid 'A'
  Tendered price = 2 x 10 900 x 1 200
  = $26 160 000.00

- For Bid 'B'
  Tendered price = 4 x 6 400 x 700
  = $17 920 000.00

G.6 Equipment Equalization

The 'equipment equalization' process is designed to compensate for differences in the scope of supply offered by various suppliers. For example, let us assume that the purchaser requires workshop equipment as part of the scope of supply and that it is included in Bid 'B' but not in Bid 'A'. If the value of the equipment is $100 000.00 we may equate the bids on the basis of scope of supply by adding $100 000.00 to the tendered price of Bid 'A' increasing it to a base price of $26 260 000.00. This is shown in item 10 in table G-1.
G.7 Adjustment for Life Expectancy of Plant

Let us assume that the life expectancy of the plant in Bid 'A' is 25 years and that of the plant in Bid 'B' is 20 years. We must account for the entire 5 years of life expectancy of the plant in Bid 'A'.

For Bid 'A':

Base price (adjusted for equipment equalization) = $26 260 000.00

Assuming that the plant is depreciated uniformly (straight line depreciation), the residual value of the plant after 20 years is:

\[ 26 260 000.00 \times \frac{5}{25} = 5 252 000.00 \]

The present worth of this residual value assuming a discount rate of 12% is:

\[ 5 252 000.00 \times 0.116107 = 609 794.00 \]

To equate the two bids, we must subtract the present worth of the residual value from the base price, which gives an adjusted base price of $25 650 206.00 (see item 12 of table G-1).

G.8 Specific Fuel Consumption

To determine the differential cost attributable to fuel consumption for the two alternatives we use the method described in Section 6.3.2. For the purpose of this example, we assume the fuel consumption figures to include generator losses, transformer losses and auxiliary power consumption.

Assume the reference SFOC (Specific fuel oil consumption) of the two alternative plants to be as follows:
For Bid 'A':

| SFOC at 50% MCR | 224 grams/kWh |
| SFOC at 75% MCR | 214 grams/kWh |
| SFOC at 100% MCR| 214 grams/kWh |

For Bid 'B':

| SFOC at 50% MCR | 226 grams/kWh |
| SFOC at 75% MCR | 217 grams/kWh |
| SFOC at 100% MCR| 220 grams/kWh |

Let us further assume that the weighting formula is as given in equation \( \text{ii} \):

\[
E_i = \frac{1E_{50\%} + 4E_{75\%} + 4E_{100\%}}{9}
\]

This formula accounts for the various load levels at which the plant is likely to be run (i.e. it does not run at full load whenever it is on line). Then for Bid 'A', the weighted average SFOC is:

\[
E_i = \frac{1 \times 224 + 4 \times 214 + 4 \times 214}{9}
= 215.1 \text{ grams/kWh}
\]

For Bid 'B':

\[
E_i = \frac{1 \times 226 + 4 \times 217 + 4 \times 220}{9}
= 219.3 \text{ grams/kWh}
\]

Now we use equation 6-4 to calculate the annual differential cost for each bid:

\[
c = (E_i - E_o) \times U \times F \hspace{1cm} (6-4)
\]

where

- \( c \) is the annual differential fuel cost
- \( E_i \) is the weighted average SFOC
- \( E_o \) is the reference SFOC
U is the energy generated in kWh/year
F is the cost of fuel in $/gram

Assume that for the first 15 years of the life of the plant we expect to generate 150,000,000 kWh per year and for the remainder 100,000,000 kWh per year. For this example let us assume that the engines in Bid A require 3% of the annual fuel used to be distillate for starting and stopping, and the engines in Bid B require 5%. If the cost of residual fuel is $0.20/kg and the cost of distillate fuel is $0.35/kg, then for Bid A the cost of fuel in equation 6-4 is given by

$$F_A = 0.97 \times 0.20 + 0.03 \times 0.35 = \$0.205/\text{kg}$$

For Bid B, the cost of fuel is given by

$$F_B = 0.95 \times 0.20 + 0.05 \times 0.35 = \$0.208/\text{kg}$$

If we take the reference specific fuel oil consumption to be 210 grams/kWh, the differential fuel costs are:

Bid 'A':
For first 15 years:
$$c = (215.1 - 210) \times 150,000,000 \times 0.205 + 1000$$
$$= $156,825$$
For the remaining 10 years of its life
the differential fuel cost is:
$$c = (215.1 - 210) \times 100,000,000 \times 0.205 + 1000$$
$$= $104,550$$

Bid 'B':
For first 15 years:
$$c = (219.3 - 210) \times 150,000,000 \times 0.208 + 1000$$
$$= $290,160$$
For the remaining 5 years of its life
the differential fuel cost is:
$$c = (219.3 - 210) \times 100,000,000 \times 0.208 + 1000$$
$$= $193,440$$
The present worth (at 12% discount rate) of the cost streams represented by these two alternatives are determined in table G-2 and G-3 respectively to be $1,317,162 for Bid 'A' and $2,356,074 for Bid 'B'.
Table G-2: Present Worth of Fuel Differential Cost
For Bid 'A'

<table>
<thead>
<tr>
<th>Year</th>
<th>Annual Differential Cost</th>
<th>Present Worth of Annual Differential Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>156 825</td>
<td>156 825</td>
</tr>
<tr>
<td>2</td>
<td>156 825</td>
<td>140 022</td>
</tr>
<tr>
<td>3</td>
<td>156 825</td>
<td>125 020</td>
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<td>4</td>
<td>156 825</td>
<td>111 625</td>
</tr>
<tr>
<td>5</td>
<td>156 825</td>
<td>99 665</td>
</tr>
<tr>
<td>6</td>
<td>156 825</td>
<td>88 987</td>
</tr>
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<td>7</td>
<td>156 825</td>
<td>79 452</td>
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<td>63 339</td>
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<tr>
<td>10</td>
<td>156 825</td>
<td>56 553</td>
</tr>
<tr>
<td>11</td>
<td>156 825</td>
<td>50 493</td>
</tr>
<tr>
<td>12</td>
<td>156 825</td>
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<td>104 550</td>
<td>7 715</td>
</tr>
<tr>
<td>25</td>
<td>104 550</td>
<td>6 888</td>
</tr>
</tbody>
</table>

Cumulative Present Worth: 1 317 162

Note: Discount rate = 12%.
Table G-3: Present Worth of Fuel Differential Cost For Bid 'B'

<table>
<thead>
<tr>
<th>Year</th>
<th>Annual Differential Cost</th>
<th>Present Worth of Annual Differential Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>290 160</td>
<td>290 160</td>
</tr>
<tr>
<td>2</td>
<td>290 160</td>
<td>290 160</td>
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<tr>
<td>3</td>
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<td>4</td>
<td>290 160</td>
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<td>20</td>
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<tr>
<td></td>
<td></td>
<td>Cumulative Present Worth 2 356 074</td>
</tr>
</tbody>
</table>

Note: Discount rate = 12%. 
G.9 Maintenance Cost

Let us assume a reference maintenance cost of $0.01/kWh.

For Bid 'A': maintenance cost = $0.008/kWh

For Bid 'B': maintenance cost = $0.015/kWh

The above values for maintenance cost would usually be assigned by the consultant evaluating the bids based on past experience and available statistics.

If we assume the same production figures shown in G-7, the annual differential maintenance cost for the two bids is as follows:

Bid 'A':

For the first 15 years, differential cost:
\[= 150\,000\,000 \times (0.008 - 0.01)\]
\[= -$300\,000\]

For the next 10 years, differential cost:
\[= 100\,000\,000 \times (0.008 - 0.01)\]
\[= -$200\,000\]

Bid 'B':

For the first 15 years, differential cost
\[= 150\,000\,000 \times (0.015 - 0.01)\]
\[= $750\,000\]

For the remaining 5 years, differential cost:
\[= 100\,000\,000 \times (0.015 - 0.01)\]
\[= $500\,000\]

The cumulative present worth of the differential in maintenance cost is shown in tables G-4 and G-5. Note that in this case the cumulative present worth of the differential in fuel cost is negative for Bid 'A'.
Table G-4: Present Worth of Differential in Maintenance Cost for Bid 'A'

<table>
<thead>
<tr>
<th>Year</th>
<th>Annual Differential Cost</th>
<th>Present Worth of Annual Differential Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-300 000</td>
<td>-300 000</td>
</tr>
<tr>
<td>2</td>
<td>-300 000</td>
<td>-267 857</td>
</tr>
<tr>
<td>3</td>
<td>-300 000</td>
<td>-239 158</td>
</tr>
<tr>
<td>4</td>
<td>-300 000</td>
<td>-213 534</td>
</tr>
<tr>
<td>5</td>
<td>-300 000</td>
<td>-190 655</td>
</tr>
<tr>
<td>6</td>
<td>-300 000</td>
<td>-170 228</td>
</tr>
<tr>
<td>7</td>
<td>-300 000</td>
<td>-151 989</td>
</tr>
<tr>
<td>8</td>
<td>-300 000</td>
<td>-127 605</td>
</tr>
<tr>
<td>9</td>
<td>-300 000</td>
<td>-121 165</td>
</tr>
<tr>
<td>10</td>
<td>-300 000</td>
<td>-108 183</td>
</tr>
<tr>
<td>11</td>
<td>-300 000</td>
<td>-96 592</td>
</tr>
<tr>
<td>12</td>
<td>-300 000</td>
<td>-86 243</td>
</tr>
<tr>
<td>13</td>
<td>-300 000</td>
<td>-77 003</td>
</tr>
<tr>
<td>14</td>
<td>-300 000</td>
<td>-68 752</td>
</tr>
<tr>
<td>15</td>
<td>-300 000</td>
<td>-61 386</td>
</tr>
<tr>
<td>16</td>
<td>-200 000</td>
<td>-36 539</td>
</tr>
<tr>
<td>17</td>
<td>-200 000</td>
<td>-32 624</td>
</tr>
<tr>
<td>18</td>
<td>-200 000</td>
<td>-29 129</td>
</tr>
<tr>
<td>19</td>
<td>-200 000</td>
<td>-26 098</td>
</tr>
<tr>
<td>20</td>
<td>-200 000</td>
<td>-23 221</td>
</tr>
<tr>
<td>21</td>
<td>-200 000</td>
<td>-20 733</td>
</tr>
<tr>
<td>22</td>
<td>-200 000</td>
<td>-18 512</td>
</tr>
<tr>
<td>23</td>
<td>-200 000</td>
<td>-16 529</td>
</tr>
<tr>
<td>24</td>
<td>-200 000</td>
<td>-14 758</td>
</tr>
<tr>
<td>25</td>
<td>-200 000</td>
<td>-13 176</td>
</tr>
</tbody>
</table>

Cumulative Present Worth: -2 511 579
Table G-5: Present Worth of Differential in Maintenance Cost for Bid 'B'

<table>
<thead>
<tr>
<th>Year</th>
<th>Annual Differential Cost</th>
<th>Present Worth of Annual Differential Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>750 000</td>
<td>750 000</td>
</tr>
<tr>
<td>2</td>
<td>750 000</td>
<td>669 643</td>
</tr>
<tr>
<td>3</td>
<td>750 000</td>
<td>597 896</td>
</tr>
<tr>
<td>4</td>
<td>750 000</td>
<td>533 835</td>
</tr>
<tr>
<td>5</td>
<td>750 000</td>
<td>476 639</td>
</tr>
<tr>
<td>6</td>
<td>750 000</td>
<td>425 570</td>
</tr>
<tr>
<td>7</td>
<td>750 000</td>
<td>379 973</td>
</tr>
<tr>
<td>8</td>
<td>750 000</td>
<td>339 262</td>
</tr>
<tr>
<td>9</td>
<td>750 000</td>
<td>302 912</td>
</tr>
<tr>
<td>10</td>
<td>750 000</td>
<td>270 458</td>
</tr>
<tr>
<td>11</td>
<td>750 000</td>
<td>241 480</td>
</tr>
<tr>
<td>12</td>
<td>750 000</td>
<td>215 607</td>
</tr>
<tr>
<td>13</td>
<td>750 000</td>
<td>192 607</td>
</tr>
<tr>
<td>14</td>
<td>750 000</td>
<td>171 881</td>
</tr>
<tr>
<td>15</td>
<td>750 000</td>
<td>153 465</td>
</tr>
<tr>
<td>16</td>
<td>500 000</td>
<td>91 348</td>
</tr>
<tr>
<td>17</td>
<td>500 000</td>
<td>81 561</td>
</tr>
<tr>
<td>18</td>
<td>500 000</td>
<td>72 822</td>
</tr>
<tr>
<td>19</td>
<td>500 000</td>
<td>65 020</td>
</tr>
<tr>
<td>20</td>
<td>500 000</td>
<td>58 054</td>
</tr>
</tbody>
</table>

Cumulative Present Worth | 6 089 932
G.10 Lubricating Oil Consumption

As is mentioned in Section 6.4, we will emphasize the inclusion of the lube oil requirement for complete oil changes. We will take the reference cost of lubricating oil changes to be $25 000.00.

Let us assume that in Bid 'A', the low speed diesel plant requires 40 000 litres of lube oil for a complete change and in Bid 'B', the medium speed plant requires 34 000 litres of lube oil for a complete change.

In addition, let us assume:

\[
\begin{align*}
\text{No. of oil changes/year for low speed diesel (Bid 'A') } & \quad 0.233 \\
\text{No. of oil changes/year for medium speed diesel (Bid 'B') } & \quad 1.08 \\
\text{Cost of oil for low speed diesel (Bid 'A') } & \quad - \text{ system oil } \$1.07/\text{litre} \\
& \quad - \text{ cylinder oil } \$1.38/\text{litre} \\
\text{Cost of oil for medium speed diesel (Bid 'B') } & \quad - \$1.26/\text{litre}
\end{align*}
\]

Then annual cost of oil (for oil changes only) for Bid 'A' is:

\[
\text{\$9,972.00}
\]

Difference between actual cost and reference cost is:

\[
(9972-25000) = - \$15,028.00
\]

Present worth of differential cost of oil over life of 25 years using a discount rate of 12\% is:

\[
(15\,028 \times 7.784) + 15\,028 = - \$132\,000
\]

The annual cost of oil (for oil changes only) for Bid 'B' is:

\[
\text{\$46,267.00}
\]

Difference between actual cost and reference cost is: \$21,267

Present worth of differential cost of oil over life of 20 years using a discount rate of 12\% is:

\[
(21\,267 \times 7.366) + 21\,267 = \$177\,919
\]
G.11 Mechanical Design Features

The methodology for assigning costs or benefits for mechanical design features is detailed in Section 6.7. Let us assume that we have been supplied the following data with the two bids under consideration:

<table>
<thead>
<tr>
<th>Evaluation Factor</th>
<th>Evaluation Method</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Engine Data</strong></td>
<td></td>
</tr>
<tr>
<td>Exhaust valve seat or valve port metal temperature</td>
<td>0 to 70</td>
</tr>
<tr>
<td>Brake mean effective pressure</td>
<td>0 to 60</td>
</tr>
<tr>
<td>Mean piston speed</td>
<td>0 to 50</td>
</tr>
<tr>
<td>Excess (continuous) brake horsepower over net brake horsepower required to maintain maximum continuous power at generator terminals</td>
<td>0 to 40</td>
</tr>
<tr>
<td>Fuel injection pump pressure</td>
<td>0 to 30</td>
</tr>
<tr>
<td>Cylinder arrangement (in-line or Vee)</td>
<td>0 to 20</td>
</tr>
</tbody>
</table>
For the oil burned in the cylinder we will assign a differential cost based on a consumption of 1.3 g/kWh for medium speed engines and 0.8 g/kWh for low speed engines. Let us further assume a production level of 150 000 000 kWh per year and an evaluation period of 20 years and an assumed base cost of $100 000.00. The cost of lubrication is as follows:

For Bid 'A':

\[
0.8 \times 150 \, 000 \, 000 \times 1.38 \times \frac{910}{910} = \$181 \, 978.00
\]
(910 is conversion from grams to litres)

Thus annual differential cost is:

$81 \, 978.00

The present worth of this over 20 years is:

$685 \, 803.00

For Bid 'B':

\[
1.3 \times 150 \, 000 \, 000 \times 1.26 \times \frac{910}{910} = \$270 \, 000.00
\]

The annual differential cost is:

$170 \, 000.00

The present worth of this over 20 years is:

$1 \, 422 \, 180.00

These costs along with the cost of oil changes are included in table G-1 as item 17.
The evaluation proceeds as follows:

<table>
<thead>
<tr>
<th></th>
<th>Bid 'A'</th>
<th>Bid 'B'</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exhaust valve seat temperature</td>
<td>70</td>
<td>0</td>
</tr>
<tr>
<td>Brake mean effective pressure</td>
<td>60</td>
<td>0</td>
</tr>
<tr>
<td>Cylinder arrangement</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>150</td>
<td>0</td>
</tr>
<tr>
<td>Per unit of possible points</td>
<td>1.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

3% of the base price is affected by this evaluation, thus, the modification to the base price is:

For Bid 'A':

the benefit (negative cost) is

\[
\text{\$ 26 260 000 x 0.03 x 1.0} = \text{\$ 787 800.00}
\]

For Bid 'B':

the adjustment is zero

This is shown as item 10 in table G-1.

**G.12 Engines Similar to Existing Engines in Plant**

We may assume a benefit of 2% of the base price for engines which are similar to those in the existing system. This benefit is based on the value of having common spare parts and the advantage of the operating and maintenance staff being already familiar with the engine type.

If we assume that the engines in Bid 'B' are similar to those existing, we add a benefit (or negative cost) of:

\[
\text{17 920 000 x 0.02} = \text{\$ 358 400}
\]
G.13 Arrangements for Training of Staff

We assume for the purpose of this example that the facilities and arrangements for staff training are similar for both sides. Thus, there is no need to assign a benefit or cost to \_\_\_. If this were necessary it would be assessed based on professional judgement and calculated as a percentage of the base price as in G.11 above.

G.14 Engine Manufacturer as Prime Contractor

We assume a benefit (negative cost) of 0.5% of the base price if the engine manufacturer is the prime contractor. This arrangement usually is more secure for the purchaser and the 0.5% represents "insurance" against future difficulties with resolving any equipment problems that may occur. The amount assigned is subject to the purchaser's perception of the importance of dealing with the engine manufacturer as prime contractor.

If we assume that in Bid 'A', the prime contractor is not the engine manufacturer, and in Bid 'B' he is, then we assign a benefit to Bid 'B'. The value of the benefit (negative cost) is:

\[ 17,920,000 \times 0.005 \]

\[ = 89,600 \]

This benefit is entered as item 22 in table G-1.

G.15 Supplier's Past Performance

Suppliers are awarded points for their past performance on delivery and response. Let us assume for this example that the supplier of Bid 'A' has a multiplier of 4 and the supplier of Bid 'B' has a multiplier of 6 on a scale where 1 represents poor performance and 10 represents excellent performance. Then since this evaluation affects 1% of the base price, benefits (negative costs) are assigned as follows:

Bid 'A':
\[
26 \, 260 \, 000 \times 0.01 \times 4 \div 10
\]
\[
= \$ \, 105 \, 040.00
\]

Bid 'B':
\[
17 \, 920 \, 000 \times 0.01 \times 6 \div 10
\]
\[
= \$ \, 107 \, 520.00
\]

This evaluation should only be used if there is a reliable record of the past performance of the suppliers involved.
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