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**Applications of Advanced Metering Infrastructure in Electricity Distribution**

Draft Report

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## Acronyms

AMCD: Advanced metering communication device

AMCC: Advanced Metering control computer

AMI: Advanced metering infrastructure

AMR: Automated meter reading

AMRC: Advanced metering regional collector

ANEEL: Agencia Nacional de Energia Elétrica

BNDES: Banco Nacional de Desenvolvimento Econômico e Social

CEMIG: Companhia Energética de Minas Gerais

CMS: Commercial management system

DSM: Demand side management

DCS: Data collection system

DT: Distribution transformer

EDGE: Enhanced data rates for GSM evolution

EDM: Electricidade de Moçambique

GSM: Group special mobile

GPRS: General packet radio services

HF: High frequency

HV: High voltage

IEA: International Energy Agency

ICT: Information and communication technologies

IRMS: Incidence resolution and management system

LAN: Local area network

LCD: Large customer department

LF: Low frequency

LV: Low voltage

MCC: Metering control center

MDM: Meter data management

MF: Medium frequency

MIP: Management improvement plan

MIS: Management information system

MV: Medium voltage

MVD: Medium voltage distribution

NDPL: North Delhi Power Limited

PLC: Power line carrier

PPL: Pennsylvania Power and Light

PREPA: Puerto Rico Electric Power Authority

RA: Rede Ampla

RF: Radio frequency

SOE: state-owned enterprise

TOU: Time of use

UHF: Ultra high frequency

US\$: dollars of the United States of America

WAN: Wide area network

## **Units of measure**

bps: bit per second

GWh: gigawatt-hour

ft: feet

GHz: giga-Hertz

Hz: Hertz

kbps: kilobit per second

kHz: kilo Hertz

kV: kilo-volt

kVA: kilo-volt-ampere

kWh: kilowatt-hour

Mbps: megabit per second

MHz: mega-Hertz

MVA: mega-volt-ampere

MWh: megawatt-hour

TWh: terawatt-hour

## Executive Summary

### What is Advanced Metering Infrastructure (AMI)

The “Smart Grid” concept refers to the deployment and integration of information and communication technologies (ICT) in the electricity network, routing power in a most effective way. Integration of ICT is already affecting the entire value chain of service delivery in the power sector, from production to consumption. ICT applications related to periodic and systematic metering, reading, monitoring and managing electricity consumption for large groups of users, referred to hereafter as “advanced metering infrastructure (AMI)” or “smart metering”, are becoming a more widespread practice not only among developed countries, but also in the developing economies. Drastic reductions in the prices of metering and telecommunication equipment in the last few years is making their adoption economically feasible, starting with large consumers and gradually moving to medium and small ones.

AMI makes it possible to achieve and sustain more efficient management of metering activities, which is crucial for an electric utility and key to the introduction of broader ICTs in power systems. Its effectiveness to reduce losses in supply, by detecting and discouraging theft, is very high, as shown by recent experiences in several developing countries (including Brazil, Honduras, India, and Dominican Republic).

By enabling real-time communication between electricity users and the utility, AMI makes possible to implement demand side management actions aimed at maximizing consumption efficiency. This is particularly relevant for medium and large consumers in all segments, both in developed and developing countries.

The implementation of AMI, together with a state-of-art commercial management system (CMS), makes pre-paid consumption of electricity possible, exactly in the same way as it works currently in the mobile phone industry. It is widely accepted that the pre-paid consumption mode has been key to expanding the use of mobile phones in low and medium income developing countries.

There are several AMI options potentially viable for each of the above-described applications, covering a wide range in terms of technical and functional specifications of hardware and software. However, the technical and economic feasibility of a specific option crucially depends on the current operational and financial performance of the involved utilities, as well as on other key characteristics (institutional, regulatory, development of communications infrastructure) of the environment in which they operate. It is very clear that, in AMI, “one size does not fit all”. The applicability and options for applying AMI or “smart meters” technology to a variety of customer management issues commonly found in public service utilities, in particular in electricity distribution companies, are described and analyzed in this report.

## **Historic evolution of systems for automation of consumption meter reading**

In the second half of the 80s several electricity companies in developed countries incorporated the automation of the reads of the consumption meters installed in their customers' premises. Adoption of that approach was driven in all the cases by the need to lower the significant costs of in-site reading, reflecting high labor costs in rich countries. In some cases, automation of reads was also considered as an adequate tool to drastically reduce the errors and related customers' complaints related to manual reads.

Those incipient systems for automation of meters reads, referred as automated meter reading (AMR), had some main common characteristics: (i) there was a one-way communication link from the meter transmitter to the receiver device (hand terminal, vehicle or fixed collector); (ii) meter reads were in general collected once every month for billing purposes; (iii) reads were processed by the billing system used by the utility, with the level of "intelligence" of that software, in general very limited.

The impressive development and expansion of information and communication technologies in the last decade made possible to evolve from the initial AMR design to a more elaborated approach for automation of collection of meters reads and their further processing, referred as automated metering infrastructure (AMI) or "smart metering". Although each expert has his own definition of these terms, there is general agreement on some minimum features and functionality of a "smart metering" system: (i) interval meters that measure consumption during specific time periods (e.g. every 15 minutes, every hour) and communicate it to the utility at least daily; (ii) a one-way communications channel that permits the utility, at a minimum, to obtain meter reads on demand, to ascertain whether electricity is flowing through the meter and onto premises, and to issue commands to the meter to perform specific tasks such as disconnecting; and (iii) any consumption meter is linked to a device that informs the customer in real time about current use, consumption during a specific period, consumption trends, and/or other information designed to help the customer manage electricity costs and usage.

In this report we refer to "Advanced Metering Infrastructure" as a hardware and software system that includes meters on one end and datausing applications on the other. Its main components are: (i) the meter; (ii) a communication device (AMCD), housed either under the meter's glass or outside the meter, that transmits meter reads from the meter directly or indirectly to the control computer; (iii) a control computer (AMCC) that is used to retrieve or receive and temporarily store meter reads before or as they are being transmitted to the company's servers; (iv) a regional collector (AMRC) that collects meter reads from the AMCD and transmits them to the AMCC (with some technologies, an AMI does not include AMRCs); (v) a local area communications network (LAN) that transmits meter reads from the AMCD to the AMRC; (vi) a wide area network (WAN), the communication network that transmits meter reads from the AMRC to the AMCC, and from the AMCC to the company's servers for processing and use. An AMI system is usually complemented by a meter data management (MDM) system and a meter data repository (MDR). MDM is a software package specifically designed to receive and process reads and other information sent by the meter (alarms, etc.) in order to enable proper and timely action by the company.

## **The AMI systems global market**

There are several providers of AMI systems in the market. All of them can use any conventional electronic consumption meter meeting international standards. Key differences between AMI systems available in the market arise from technology used for communications between the main components, from the meter to the company's server.

Currently two communication techniques are clearly predominant in AMI systems available in the market: (i) power line carrier (PLC); (ii) radio-frequency (RF).

Communication services provided by each of those techniques can be: (i) one-way: only from the meter to the server or in the opposite sense; (ii) two-way: data can be transmitted both from the meter to the server and in the opposite sense, allowing to operate the meter and attached equipment and provide information to the end consumer. Main characteristics of each technique are described in detail in Section 3 and Annexes of the report.

Until the end of 2009 more than 12,000 AMR projects around the world have been implemented or announced. Most of them should not be considered AMI systems, as they are using just one-way communication Power Lines Carrier (PLC) or Radio Frequency (RF) systems. The main objective of most of those projects is to collect meter reads for billing purposes.

245 AMI projects have been recently announced by public service companies worldwide. The total number of remotely metered endpoints reaches 631 million. The number of electricity companies that have announced AMI projects is 177, totaling 569,600,000 endpoints. Only 73 projects (122 million endpoints) have defined the communications technology to be applied.

## **Key aspects to consider for the evaluation of performance of AMI systems**

The performance of an AMI system and its adequacy to provide a determined service in a specific area can be evaluated through the analysis of a set of key aspects. Some of the most relevant are

- Architecture and technological infrastructure
- Adaptability to field topography of the served area
- Adaptability to the operational condition of customers' connections
- Adaptability to environmental conditions
- Adaptability to operational condition of the electricity network
- Adaptability to network length
- Adaptability to the type of distribution transformers (low or high capacity)
- Information transmission capacity and operational reliability
- Maintenance complexity
- Information security/Recovery systems

- Ability to identify faults in the communication system
- Installation
- Compatibility with most meters in the market
- Ability to operate equipment in the distribution network
- Cost per installed unit
- Maintenance costs
- Experience in application of the technology

An analysis of the performance of each type of AMI system regarding each of these key aspects is presented in Section 4 and Annex 2 of the report.

### **Applications of AMI systems in electricity companies in World Bank country clients**

#### Sustainable reduction of non-technical losses

Market served by electricity companies is in general characterized by the presence of the “Pareto or ABC effect”. Namely, a small group of large consumers (usually less than 1 percent of total number of customers) supplied at high (HV) and medium voltage (MV) accounts for a big share of revenues of the company (30 percent or more). If the largest consumers supplied at low voltage (LV) are added, 3 to 5 percent of total number of customers account for 50 percent or more of total revenues. In order to ensure the financial health of the company it is of utmost importance first to permanently remove theft and fraud in electricity supply to the largest HV and MV consumers, and then gradually reach the same condition in supply to the largest consumers connected to low voltage networks. This sequencing of operations has been successfully implemented by several utilities in Latin American countries that reformed their respective power sectors in the 1990s, through a combination of good management practices and the application of ICT tools available at that time.

Although at the time of those reforms the application of remote metering systems was well known, it was still unfeasible due to high investment costs of metering equipment and limited development of communication systems. Thus, the utilities implementing successful action plans to reduce losses had to include systematic monitoring through field inspections, carried out by their best staff (in terms of technical skills and personal integrity), as a critical component to promote market discipline. This approach implies big expenditures and, more importantly, it does not ensure a sustainable solution to the problem. The case of Brazil, described in detail in Section 5 of the report, is a clear example supporting this statement.

While the fundamentals concerning the legal and institutional aspects of the successful initiatives implemented in several developing countries in the 1990s remain fully valid, reengineering of business

processes must be dynamic and continually adapt to technological evolution, particularly with respect to ICT and, more specifically to AMI.

Large-scale application of AMI, starting with large consumers and gradually extending to medium and small ones, is an extremely effective tool to detect and discourage theft and other ways of unmetered consumption, as shown by the recent experience in developing countries. It has the following positive impacts (in general significant in countries where levels of corruption are big):

- *“Watchdog” effect on users.* Users become aware that the utility can monitor consumption at its convenience. This allows the company fast detection of any abnormal consumption due to tampering or by-passing of a meter and enables it to take corrective action. The result is consumer discipline. This has been shown to be extremely effective with all categories of large and medium consumers having a history of stealing electricity. They stop stealing once they become aware that the utility has the means to detect and record it. Recent experience in Brazil, Dominican Republic, Honduras and India shows that consumers stop stealing if they face the risk of social condemnation. More importantly, they do not go back to stealing electricity.

- *Enhancement of the company’s corporate governance and anti-corruption efforts.* Instances of theft by large consumers usually involve collusion between them and the meter readers (the bottom of a pyramid within the utility that can reach high management levels). AMI eliminates the need for regular field operations (such as meter readings and service disconnections), thus greatly improving governance and reducing room for corruption. Deployment and use of AMI also makes information about consumption transparently and timely available to both the clients connected to the system and the management of the utility (at all levels). Any abnormal change in consumption patterns due to tampering or by-passing of a meter can be detected, enabling the utility to take immediate corrective actions. This provides discipline for consumers prone to theft and fraud to change behavior, stopping tampering meters and stealing, because of threat of being detected and punished.

Implementation of an automated metering project is in general a phased process. It must always start with the medium and high voltage consumers, accounting for a big share of revenues of the company (30 percent or more). The financial health of the company crucially depends on protecting those revenues. For that purpose, it becomes necessary to ensure that all consumers in this group are permanently billed according to their actual consumption.

Total number of HV and MV consumers is in general low (a few thousand), and their geographic location is dispersed. Thus, implementation of automated metering for this group does not require the features of a massive solution. Usually each consumption point is remotely metered, read and monitored through an individual link. The predominant approach for communication between meters and servers is the use of the cellular network. A communication modem is installed within the meter or externally attached to it. The main manufacturers of electricity consumption meters have developed standard products including

those modems. They also went into strategic partnership with companies providing software specifically designed to handle the data transmitted through the communication links and read them from the company's server. This software is sometimes referred as "Data Collection System (DCS)".

The application of cellular networks for data communication implies to take proper consideration to some technical aspects, which are presented in Section 5 of the report.

Typical market prices of internal modems for meters are in the range of US\$ 150 to US\$ 200. For an external modem the price varies from US\$ 250 to US\$ 400, depending on the type of GSM technology used by the device. The price of the DCS varies from US\$ 50,000 to US\$ 150,000. The operating costs (price paid by the distribution company for the use of the cellular network) vary from country to country, and sometimes from region to region in the same country. Currently, a typical price could be around US\$ 10 per month and per connected point. All the figures in this paragraph are provided only for illustrative purposes. Impressive developments in communication technologies, if accompanied by unrestricted competition, can create drastic changes in very short time periods.

A more expensive solution consists of duplicating or "externalizing" the metering system by installing a new one (including current and voltage metering transformers) in a fully sealed box located outside the customer's premises. This solution is used when the customer does not allow the utility to access the existing metering system (in spite it is owned by the distribution company) to replace its components by new ones with AMI capabilities. This has occurred in certain regions of Brazil, where the justice system does not function properly. Installation of a new system outside the premises costs about US\$5,000 per point of supply. Some companies adopt this expensive solution as the basic option considering its extremely high effectiveness: experience shows it makes almost impossible to steal electricity and eliminates any chance of interference by the customer. And the cost is very low when compared to the amount of revenues permanently protected.

The rate of return of projects for Automated Meter Reading (AMR) of high and medium voltage consumers is extremely attractive in most cases. Although it depends on average tariff levels and amounts of electricity previously stolen, some basic figures illustrate their effectiveness. A US\$ 300 to US\$ 400 cost to implement a remote metering system using existing facilities is equivalent to 3,000 to 4,000 kWh at an electricity price of US\$0.10 /kWh. In the case of a large user stealing this amount every month (not very significant for a customer with recorded consumption in the range of 10,000 to 20,000 kWh a month), the investment will be recovered in one month through billing of the previously unmetered consumption.

Even being more expensive, the solution based on "externalization" also has in general a very high rate of return, because a large customer blocking access to the metering system on his premises is most likely to be engaged in fraudulent behavior and not paying fully for electricity consumed.

Despite its very high economic and financial attractiveness, there are some barriers to overcome to successfully implement remote metering of high and medium voltage consumers. Successful cases in several developing countries evidence that when a distribution company has a high amount of non-technical losses, a significant share corresponds to supply to large consumers. Potential undue earnings arising from systematic under-billing of those consumers are actually enormous, and this creates incentives for collusion between customers and utility's staff. Managing a company ignoring this circumstance is in practice equivalent to promote, or at least tolerate, the risk of those corrupt behaviors.

Experience also shows that companies that have incorporated remote metering of their high and medium voltage consumers fully eliminated non-technical losses in supply to this segment. There are many strong reasons to adopt this approach without any delay, particularly if the company is in financial distress due to high non-technical losses. However, it is quite usual to find utilities in developing countries facing high non-technical losses, but whose management is reluctant to implement this solution. There may be several explanations for this attitude. The less negative is the "monopolistic culture". In some cases (particularly state-owned enterprises) nothing changes for managers if the performance of the company is good or bad, as monopolies don't fail. Thus, they keep the "statu-quo", and do nothing to reduce losses. In other situations, top management is directly involved in the big side-business related to systematic under-billing of large consumers. It is quite easy to identify these cases: managers will argue that supply to that segment is closely monitored by them, and they can assure there are no commercial losses (although they will not be able to provide evidence of this statement). Thus, they find unnecessary to spend money in remote metering. Anyway, the case of the Brazilian company CEMIG, described in Section 5 of the report, provides a very strong argument to overcome reluctance to implement remote metering of the large consumers segment.

Several recent cases become source of relevant lessons on some key elements that must be addressed in order to ensure successful implementation of a remote metering system for large consumers (in addition to the technical aspects in Section 5). They refer in essence to company's management, but also include issues related to scope of the metering system.

On the one side, the distribution company should create a "Large Customer Department (LCD)", responsible for managing all aspects of its interaction with large customers (metering, billing, collection, attention of claims related to quality in electricity supply). Its manager must be an expert with wide professional experience in the commercial management of large customers. Organizational structure and operational procedures of LCD should ensure that each large consumer receives personalized attention from a single "contact person" in the company, who should be responsible for addressing all the issues in the interaction, taking care of all the internal arrangements needed for that purpose. A "Metering Control Center (MCC) should be created within the LCD, with the specific assignment of operating the remote metering system for large consumers. Staff of the MCC should be young engineers, trained by system provider.

On the other side, a specific “intelligent” software, usually referred as “Meter Data Management (MDM)” must be incorporated by the company to make possible efficient performance of the MCC. Most of the providers of remote metering systems are companies based in developed countries, where the main use is for periodic (monthly or bimonthly) read of consumption for billing purposes. Thus, those systems include a very simple software package, designed to properly manage those reads. However, in general that software is completely inadequate to carry out systematic analysis of the daily consumption of a large customer and compare it with reference values, which is the key feature for timely detection and correction of abnormal situations (fraud, theft, etc.). Thus, incorporation of a software package specifically designed to make possible an efficient development of that analysis for each and all consumers in the system, presenting as alarms pre-parameterized deviations in consumption from a standard pattern, is absolutely crucial to effectively reduce non-technical losses. Some cases described in Section 6 of the report show that the consequences of not incorporating the MDM can be devastating.

In addition to the creation of the LCD and incorporation of the MDM, organizational arrangements for proper maintenance of all the components of the AMI system and ensure its sustainable good performance need to be defined and implemented. An approach that is becoming widely used by several companies in developing countries includes contracting the supply, installation, commissioning and maintenance of all the components (hardware and software) of the AMI system during a 2 to 5 year period with a special purpose group, formed by companies providing skills in meter manufacturing and installation and MDM software.

In some companies remote metering programs are limited to the high and medium voltage consumers. However, as implementation costs continue to decrease, a broader scope is becoming predominant in developing countries to ensure that the greatest possible sustainable reduction of non-technical losses is actually achieved. All the low voltage customers with contracted demand or monthly energy consumption above a certain threshold are included in the program. Typical values are 10 kW demand and 500-1000 kWh/month, although there are wide variations from case to case. The decision on the threshold for a specific case requires an in-depth analysis of the composition of the market (number of customers in each consumption interval), average tariff, etc. The concept supporting this expansion based on individual consumption is exactly the same applied for large high and medium voltage customers: sustainable protection of revenues generated by supply to a small group of users that represent a large share of total sales, ensuring the inexistence of non-technical losses.

Some companies adopt a slightly different approach. Implementation of AMI to low voltage consumers is driven by consumption per customer combined with geographic location. The zones showing the largest values of amount of injected energy/customer are identified and AMI is implemented to each and all of the customers connected to a same distribution transformer (DT) and to the LT terminal of the transformer (to monitor energy flowing through it). This is a more expensive option, as all consumers supplied by a same transformer are included in the AMI program, regardless of their consumption. However, it makes possible to carry out energy balances at the DT level, by comparing records of the

meter installed in this equipment with those of the consumers connected to it, if this information is available. This ensures immediate detection of any non-technical loss in the circuit supplied by the DT, allowing timely adoption of the required corrective action.

Regardless of the criterion adopted to define it, the expansion of the remote metering program to reach large low voltage consumers implies that the total number of points increases to values in the range from 20,000 to 150,000 or more. Capacities and performance requirements of the hardware and software infrastructure needed to properly acquire, transmit and manage the amount of data related to this new dimension of the metering system are completely different from those used if the scope is a few thousand of high and medium voltage customers. These enhanced components characterize the AMI approach.

As the total number of points to be remotely metered and monitored moves to 20,000 or more, it is necessary to use more advanced communication systems, in general based on PLC or RF technologies. Besides, the effective implementation of a state of art MDM software making possible to process such amount of data, detect any potentially abnormal condition and timely adopt the appropriate corrective action becomes absolutely crucial.

Communication infrastructure requirements and related investment and operating costs for implementation of AMI to individual large low voltage customers depend on their geographic location. It is clear that costs tend to increase if consumers are sparsely located in the served area, as this obliges to implement more communication links. However, in general large low voltage customers are concentrated in medium and high income areas. This makes possible to design and implement optimized communication schemes, based on PLC or RF technologies. The most adequate option depends on the location of the targeted customers, geographic constraints and other aspects described in Section 4. A fully case-specific analysis needs to be carried out by a competent expert, in a very short period. Time is critical. The worst approach is to consider implementation of AMI as a long term project.

Current market prices of AMI systems for low voltage customers are in the range of US\$ 80 to US\$ 130 per connected point, including communications hardware and MDM software. A device allowing remote disconnection and reconnection can be added at US\$ 50 to US\$ 70. These are direct implementation costs of the AMI system. Sometimes the customer is already metered using electromechanical equipment. Thus, the installation cost of the new meter must be added (typically US\$ 50 to US\$ 60).

If AMI is also installed in DTs to enable energy balances, total investment costs per customer may reach US\$ 250 to US\$ 350, depending on the topology of the distribution network. The upper bound of this interval corresponds to 3,500 kWh consumed at a tariff rate of US\$ 0.10 per kWh. This is less than the amount consumed in 6 months by a customer with 600 kWh/month average consumption. A one-time investment equivalent to that monthly billing ensures that the customer will be billed according to his real consumption during the whole economic life of the AMI system (around 15 years).

In Section 6 of the report, several representative cases of the application of AMI for sustainable reduction of losses in electricity distribution are described in detail.

#### AMI as a component of the distribution system for non-manageable (high risk) areas

AMI is a key component of the approach called medium-voltage distribution (MVD), which is adopted for construction and operation of electricity networks used to supply consumers located in areas where access to the service company is constrained due to safety or other reasons. MVD was initially designed and implemented by the Brazilian company Ampla, providing electricity service to 2.3 million customers in the Brazilian state of Rio de Janeiro. The case is described in detail in Section 6 of the report. 670,000 out of 2.3 million Ampla's customers are located in slums where crime associated with drug traffic makes regular operations almost impossible. In 2003 the company started to develop a new approach to serve those areas, based on a specific network design to prevent theft, combined with the application of AMI. The company named it "Rede Ampla (RA)". Other similar approaches for network design are usually referred as "medium voltage distribution (MVD)". In MVD networks, each individual consumer connection starts directly from the low voltage terminal of a small capacity single-phase DT, and is laid above the medium-voltage line. Thus, the low-voltage grid is eliminated. Besides, meters are not installed at customers' premises, but in an armored box on the same pole used for the DT, and AMI is used to read their consumption records. The RA is a combination of the MVD and AMI. Between 2003 and 2009 Ampla implemented it for the supply to more than 300,000 consumers living in dangerous slums. RA is an expensive solution requiring significant investments both in new distribution networks and AMI. Investment ranges from US\$ 400 to US\$ 600 per customer, depending on density and other factors. But it is the cheapest *sustainable* solution in these areas. Experience shows that a solution requiring the company to perform activities at the site does not work, as access to the area is constrained. Distribution schemes following the same principles of the Ampla case were implemented by several distribution companies in other developing countries in Latin America and South Asia.

#### Prepaid consumption in low-income areas

Application of AMI, together with a commercial management information system (CMS), makes implementation of pre-paid consumption of electricity for low-income consumers, which is generally a very good commercial option for them and for the utility. Voluntary pre-paid consumption proved to be a viable option to make possible access and sustainable supply to low-income users. It also makes a more transparent use of direct subsidies possible, when necessary.

AMI enables replication in the power sector of the tremendous success of pre-paid consumption in the mobile phone industry—key to expanding use of mobile phones in developing countries. Credit bought by consumer is loaded in his account in the CMS; many options are available for purchase and loading, including use of mobile phones. The company can easily implement operational procedures allowing the customer to have access to the remaining credit, receive alert messages from the company when the credit

is about to expire, buy new credit, receive disconnection message, etc. The company can apply remote disconnection and reconnection included in the AMI devices used for low-voltage consumers in cases of credit expiration and non-renewal in the same way pre-paid mobile phones work.

The AMI approach for pre-paid consumption has several significant advantages compared to the classic pre-paid card meters widely used in South Africa and other countries. Two very important ones are: (i) significantly lower hardware costs; and (ii) permanent monitoring consumption allowed by AMI, which is not possible with the classic card meter. With a card meter, the company has no information on real time consumption while the user has credit and the cardholder can by-pass the meter without being detected, unless field inspections are performed. Conventional prepayment meters protect only sales and revenues related to the prepaid amounts. They proved to be a successful tool to promote consumers' discipline to pay for electricity in cases where theft was not a major problem. They are also a very good option for supply to new users in rural areas (the case of Morocco is an impressive example). However, they are not aimed at protecting revenues related to the amounts of energy actually consumed by the user under the prepayment regime. Their contribution to loss reduction is actually limited and, in practice, they don't solve the main problem in areas where theft and willingness to incur in irregular consumption are high.

AMI pre-paid consumption has all the advantages and features of the classic option and adds to them the effectiveness of the remote metering tool to achieve a sustained reduction of non-technical losses.

Application of AMI enabled prepayment schemes has been limited. They started to be implemented in 2008 by Ampla but could not achieve significant progress due to a legal constraint: utilities must inform their customers 15 days in advance of the date of a service disconnection related to commercial debts. This is completely contradictory with the concept of prepaid consumption. The elimination of that barrier is currently being discussed by Brazilian lawmakers.

In general, application of prepaid consumption schemes should be considered once the overall problem of high non-technical losses is solved, as this is the key aspect jeopardizing the financial viability of the distribution company.

#### Demand side management actions to maximize efficiency in electricity consumption

AMI applied to medium and large customers in all consumers' categories can allow the optimization of electricity use, by offering users relevant real-time information on price changes, duration of peak periods, cumulated consumption, alerts, etc. Recent experience, both in developed and middle income developing countries, illustrates that medium and large residential consumers may be responsive to clear and timely information on pricing options **if they perceive potential benefits for them**, in the same way as large industrial and commercial consumers. Those pricing options range from the classic "static" two-charge (demand and energy) time-of-use tariffs to the more sophisticated dynamic pricing options.

AMI driven demand side management (DSM) applications appear as a natural second step in utilities in developing countries facing significant theft and fraud, once this situation is eliminated with the help of that tool. It focuses on energy efficiency from the country-level standpoint. It is well known that a pricing system providing users with the right signals on actual costs of supply is an absolutely critical condition to promote efficiency in consumption. And by setting up a direct link between the consumer and the utility, AMI makes possible to promote energy efficiency.

Although there is general agreement on the above-described concepts, the effective implementation of AMI enabled dynamic pricing DSM has been until now limited to a set of pilot tests, mainly in the United States. Application of dynamic pricing in developing countries has been limited to the use of time-of-use (TOU) tariff schemes for medium and large customers in some or all categories, including sometimes both power demand and energy charges (binomial rates). Residential consumers are in general free to choose between those TOU schemes and the conventional system based on a uniform energy rate. In practice, most residential consumers are metered using electromechanical devices that only record energy (uniform tariff). Utilities showing acceptable levels of total losses avoid changing the meters before they reach the end of their economic lives. This is particularly evident if the tariff regime is based on recognition of replacement costs, which is the predominant situation in Latin America. In this case, the utility has strong incentives to avoid the replacement of equipment that could continue to be used without deteriorating service quality. As an example, in Brazil only 7.39 percent of the total number of electricity consumption meters is electronic. More than 80 percent of the meters countrywide have 10 years or less.

Recent experiences (Brazil rationing in 2001, Chile big increases in electricity tariffs in 2008) show that medium and large residential consumers are more responsive to significant changes in overall average tariff level (monthly bill) than to TOU options. Those consumers will significantly reduce their consumption in a short time if exposed to big increases in the average tariff level. But they are likely to adopt complex TOU regimes only if this implies a significant economic benefit for them (in terms of the amount they pay for electricity supply) without obliging them to implement changes adversely affecting their quality of life. Thus, the effective viability of DSM actions based on TOU schemes depend on the calculation of the rates in each block, which should be carried out in a way that ensures they reflect total costs of efficient service provision in each of them. Costs should be computed considering long-term expansion of generation, transmission and distribution facilities needed to provide service meeting quality standards set in the applicable regulations. This requires the development of planning studies aimed at identifying options available for the country to expand its power sector and building-up scenarios to be evaluated, taking into consideration aspects such as security of supply, environmental constraints, the impacts of climate change, etc. Total costs of efficient supply arising from the technical and economic evaluation of each scenario, and their variation in time of day, will determine the effective viability of DSM programs. Although the evaluation is fully case-specific, some general comments can be made. On one side, generation costs, which already represent a major share (70 percent or more) of total rates paid by end consumers in most countries, are likely to increase their impact on the average tariff level in the medium and long term. This is a consequence of future global scenarios characterized by high prices of

energy primary resources and conversion equipment. In this context, the relative impact of network costs on average tariffs will decrease on time. Thus, if generation costs do not change significantly in time of day (which is the case in systems with large installed capacity in hydropower plants or low operating cost base load thermal stations), TOU schemes based on real costs of supply are unlikely to be attractive. On the contrary, TOU regimes could be convenient for customers if their rates reflect large differences in generation costs in the same day arising from the use of peak plants running on expensive fuels.

It can be stated that the effective application of AMI in dynamic pricing, time of use tariffs and other options for DSM and demand response programs crucially depends on the viability of designing and implementing programs that are perceived by customers as convenient for them. And this implies to get significant reductions in electricity bills with limited negative impact on comfort. If well designed pricing systems are applied, the viability of the DSM programs will be determined by the amount of differences between total costs of efficient supply in day periods and the ability of customers to manage their consumption pattern to take proper advantage of those differences. The technological feasibility is well known, but it is far from being the critical element.

## **Applications of Advanced Metering Infrastructure in Electricity Distribution**

### **Objective**

This document reviews experience by electricity distribution companies in the application of systems for remote read of customers' consumption meters and other related features, referred as Advanced Metering Infrastructure (AMI) and provides examples of sustainable positive results.

### **1. Advanced Metering Infrastructure**

The “Smart Grid” concept refers to the deployment and integration of information and communication technologies (ICT) in the electricity network, routing power in a most effective way. As stated in a recent report sponsored by the U.S. Department of Energy<sup>1</sup>, the deployment of smart grids will allow to “broadcast” power bringing the formidable opportunities of the Internet to the power utilities and the grid. This will enable the transformation of the power industry from a few centralized power generators to a large number of “interactive” users, routing power in a more optimal way and allowing the industry to achieve their full potential of grid modernization. This move is expected to change the industry's overall business model, as well as the relationships with all stakeholders, involving and affecting power utilities, regulators, energy service providers, vendors and all consumers of electric power.

Integration of ICT is already affecting the entire value chain of service delivery in the power sector, from production to consumption. It is having a significant and increasing impact on electricity distribution and retail supply, a sector where technological innovation has been historically gradual, at least in relation to the main network assets. ICT applications related to periodic and systematic metering, reading, monitoring and managing electricity consumption for large groups of users, referred to hereafter as “advanced metering infrastructure (AMI)” or “smart metering”, are becoming a more widespread practice not only among developed countries, but also in the developing economies. Drastic reductions in the prices of metering and telecommunication equipment in the last few years is making their adoption economically feasible, starting with large consumers and gradually moving to medium and small ones. AMI represents an interesting interface between, or confluence of, the ICT and energy sectors. For the

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<sup>1</sup> “Exploring the imperative of revitalizing America’s electric infrastructure: The Smart Grid: An Introduction. How a smarter grid works as an enabling engine for our economy, our environment and our future”. Prepared for the U.S. Department of Energy

power sector, the intelligence of a communications network, like the Internet, overlaid over power grids is essentially embedding the architecture with a data network that helps it run more "smartly".

AMI makes it possible to achieve and sustain more efficient management of metering activities, which is crucial for an electric utility and key to the introduction of broader ICTs in power systems. Its effectiveness to reduce losses in supply, by detecting and discouraging theft, is very high, as shown by recent experiences in several developing countries (including Brazil, Honduras, India, and Dominican Republic). It can also significantly lower the operating costs of billing handling and reading. This was indeed one of the key factors driving its application in developed countries, with Italy being one of the earliest and largest commercial scale cases at the retail level at the beginning of this century. However, experience in developing countries shows that reduction of billing handling and reading costs alone may not justify investments in AMI.

Besides, by enabling real-time communication between electricity users and the utility, AMI makes possible to implement demand side management actions. Consumers are able to receive timely information on prices, a powerful incentive toward reducing their energy costs, and maximizing consumption efficiency. This is particularly relevant for medium and large consumers in all segments, both in developed and developing countries.

The implementation of AMI, together with a state-of-art commercial management system (CMS), makes pre-paid consumption of electricity possible, exactly in the same way as it works currently in the mobile phone industry. It is widely accepted that the pre-paid consumption mode has been key to expanding the use of mobile phones in low and medium income developing countries. Even recognizing the different nature of the two services, some relevant cases show that a well-designed and implemented voluntary pre-paid consumption scheme is a good option for sustainable electricity supply to the low-income segments of the population.

Large-scale application of AMI can significantly contribute to sustainable development and efficient performance of power sector in developing countries, as well as to maximize efficiency in electricity consumption worldwide. Energy efficiency is identified by the International Energy Agency (IEA) in its *World Energy Outlook 2008* as one crucial action to tackle climate change.

On the one hand, AMI can help improving performance and enhancing corporate governance of power utilities in developing countries at an early stage of reforms characterized by low quality of institutions and wide spread corruption, which in turn can contribute to high levels of non technical losses. Such a poor performance can jeopardize the financial sustainability of the whole power sector, by hindering other reforms, including the application of tariff systems reflecting full costs of efficient supply. Improvement of quality of services made possible by the deployment of smart grids can in turn also help to make those broader reforms more acceptable to customers, who would be willing to pay more in return for a better service.

On the other hand, AMI can help power utilities in more developed countries that have already achieved an efficient operational and financial performance to address the challenges posed by climate change, by maximizing the scope and effectiveness of demand management. A permanent two-way communication set between the utilities and their large and medium customers makes possible to provide those users with information on near real-time costs of supply and other services (such as remote control of specific appliances and devices). This becomes the most effective way to maximize efficiency in their electricity consumption.

There are several AMI options potentially viable for each of the above-described applications, covering a wide range in terms of technical and functional specifications of hardware and software. However, the technical and economic feasibility of a specific option crucially depends on the current operational and financial performance of the involved utilities, as well as on other key characteristics (institutional, regulatory, development of communications infrastructure) of the environment in which they operate. It is very clear that, in AMI, “one size does not fit all”. This enhances the importance of a good knowledge of the currently available market products, their functionality and performance, and the conditions that make possible to maximize effectiveness in their application in the power sector.

The objective of this report is to illustrate the applicability and options for applying AMI or “smart meters” technology to a variety of customer management issues commonly found in public service utilities, in particular in electricity distribution companies. The study is focused on the identification and description of technological options available to consumption meters, communication systems, and software packages to manage data provided by AMI, and its interaction with other management information systems used by the utility, etc. AMI feasible options for each specific application are compared from an economic and technical perspective, and the infrastructure conditions required for effective performance of the system are identified.

## **2. Historic evolution of systems for automation of consumption meter reading**

In the second half of the 80s several electricity companies in developed countries incorporated the automation of the reads of the consumption meters installed in their customers’ premises. Adoption of that approach was driven in all the cases by the need to lower the significant costs of in-site reading, reflecting high labor costs in rich countries. In some cases, automation of reads was also considered as an adequate tool to drastically reduce the errors and related customers’ complaints related to manual reads.

Those incipient systems for automation of meters reads consisted of the installation of a radio frequency transmitter (RF), either within the meter or attached externally to it. That transmitter continually sent the information on energy consumption recorded by the meter, which was collected through the use of hand

terminals (handheld) or devices installed in a vehicle, in what is referred as “drive-by” systems. The data collected by the terminal were then transferred to the company's servers through automated downloading processes without any human intervention. In a second stage, the basic design was upgraded by incorporating the data concentrator, which is a device physically installed close to a group of meters, collecting the data recorded by them and sending that information to the company's servers for automated download. In technical terms, the data concentrator is a simple collector of information. In both stages communication is one-way and data are transmitted from the meter to the collector using one of a number of different communication techniques, such as radio signals, power-line communications, or satellite.

Those systems, referred as automated meter reading (AMR), had the following main common characteristics: (i) there was a one-way communication link from the meter transmitter to the receiver device (hand terminal, vehicle or fixed collector); (ii) meter reads were in general collected once every month for billing purposes; (iii) reads were processed by the billing system used by the utility, with the level of “intelligence” of that software, in general very limited. Those AMR systems showed to be effective to lower costs of periodic reads for billing, as well as to reduce the number of customers' complaints due to errors in reads and related wrong bills. These were the main problems faced in utilities in developed countries.

The situation is different in developing countries, where labor costs are lower but non-technical losses in electricity supply continue to be a big problem in some regions. Although some companies incorporated the AMR approach, accurate reads of meters for billing purposes was in general not addressing a critical problem: big amounts of non-technical losses (unmetered consumption due to meter tampering and/or bypass, illegal connections to the electricity network and other causes), which jeopardize the financial viability of the utilities facing them.

The impressive development and expansion of information and communication technologies in the last decade made possible to evolve from the initial AMR design to a more elaborated approach for automation of collection of meters reads and their further processing, within the “Smart Grid” concept described in Section 1. As stated in that section, this approach is referred as automated metering infrastructure (AMI) or “smart metering”. Although each expert has his own definition of these terms, there is general agreement on some minimum features and functionality of a “smart metering” system: (i) interval meters that measure consumption during specific time periods (e.g. every 15 minutes, every hour) and communicate it to the utility at least daily; (ii) a one-way communications channel that permits the utility, at a minimum, to obtain meter reads on demand, to ascertain whether electricity is flowing through the meter and onto premises, and to issue commands to the meter to perform specific tasks such as disconnecting; and (iii) any consumption meter is linked to a device that informs the customer in real time about current use, consumption during a specific period, consumption trends, and/or other information designed to help the customer manage electricity costs and usage.

Some experts in the industry further restrict “smart metering” by requiring: (i) a two-way communications channel between the utility and the meter that can be activated from either end; (ii) stand-alone data collection and processing software, different from the existing billing system; (iii) deployment of an advanced application over a substantial percentage of customer class.

In this report we will refer to “Advanced Metering Infrastructure” as a hardware and software system that includes meters on one end and datausing applications on the other. Its main components are:

- (i) The meter.
- (ii) A communication device (AMCD), housed either under the meter’s glass or outside the meter, that transmits meter reads from the meter directly or indirectly to the control computer;
- (iii) A control computer (AMCC) that is used to retrieve or receive and temporarily store meter reads before or as they are being transmitted to the company’s servers. The information stored in the AMCC is available to log maintenance and transmission faults and issue reports on the overall operational condition of the AMI system;
- (iv) A regional collector (AMRC) that collects meter reads from the AMCD and transmits them to the AMCC. With some technologies, an AMI does not include AMRCs.
- (v) A local area communications network (LAN) that transmits meter reads from the AMCD to the AMRC; in some cases AMCDs directly communicate with AMCCs
- (vi) A wide area network (WAN), the communication network that transmits meter reads from the AMRC to the AMCC or, in some systems from the AMCD directly to the AMCC, and from the AMCC to the company’s servers for processing and use:

An AMI system is usually complemented by a meter data management (MDM) system and a meter data repository (MDR). MDM is a software package specifically designed to receive and process reads and other information sent by the meter (alarms, etc.) in order to enable proper and timely action by the company. MDR stores data for future use. There is some ongoing technical debate on if MDM and MDR should be considered as components of the AMI system. This debate sounds irrelevant as MDM is absolutely crucial to fully use the powerful functionality of an AMI system. Many utilities that omitted to incorporate the MDM together with the AMI discovered that they were unable to use the main features of the metering system, as shown in the cases described in Section 6.

### **3. AMI systems available in the market: technical and functional characteristics**

There are several providers of AMI systems in the market. All of them can use any conventional electronic consumption meter meeting international standards. Key differences between AMI systems available in the market arise from technology used for communications between the main components,

from the meter to the company's server. Thus, the analysis in this section is focused on those communication technologies, their functionality and features, and the eventual constraints they impose for further expansion of scope of the AMI, once they are used in the initial phase.

Currently two communication techniques are clearly predominant in AMI systems available in the market:

- Power line carrier (PLC)
- Radio-frequency (RF)

Communication services provided by each of those techniques can be:

- One-way: only from the meter to the server or in the opposite sense
- Two-way: data can be transmitted both from the meter to the server and in the opposite sense, allowing to operate the meter and attached equipment and provide information to the end consumer.

Main characteristics of each technique are described in the following sub-sections

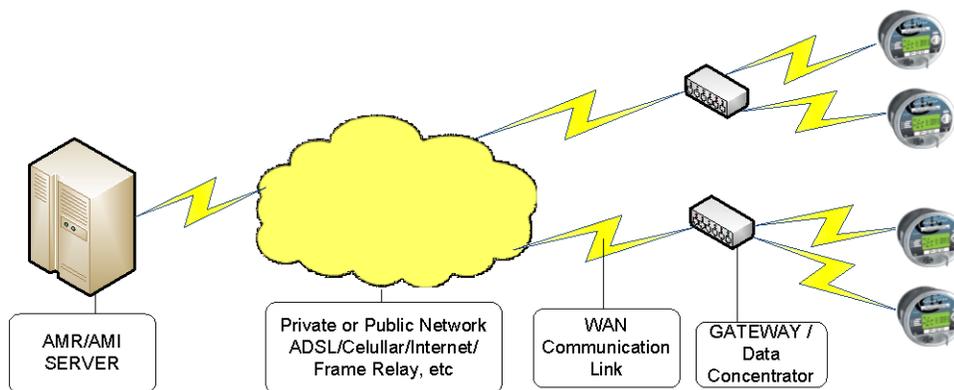
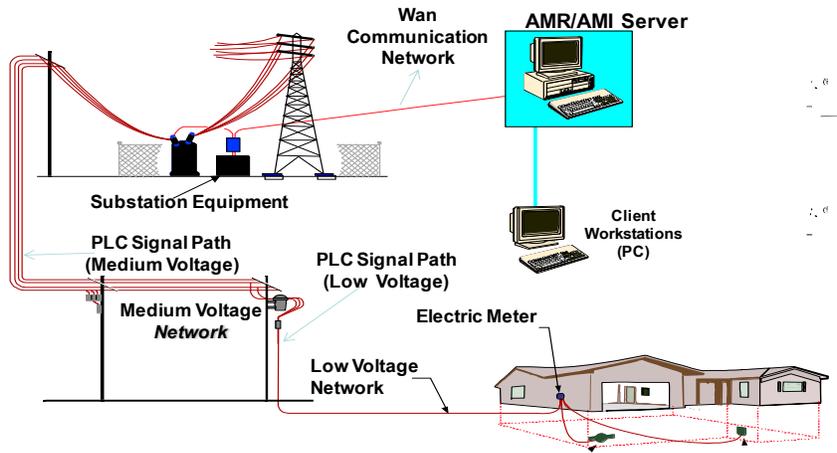


Figure 3.1: Functional diagram of an AMI system

### 3.1 Power line carrier

High voltage PLC systems started to be implemented by electricity companies in the 70s for internal use, mainly to transmit signals for remote operation of equipment installed in power lines and substations and their protection devices. They were also used to provide voice communication. In a second stage, the application of PLC was extended to distribution equipment, operating in medium and low voltages. Use of PLC for AMI corresponds to this second phase. Some systems use exclusively low voltage (LV) or medium voltage (MV) lines, while others are able to transmit signals across lines in both voltage levels.

Some of the two-voltage systems incorporate specific equipment to make the signal pass or “jump” from LV to MV, while others perform this without the need of any physical element.



**Figure 3.2: PLC systems**

### 3.1.1 Typical PLC systems

Based on their range and speed of transmission, PLC systems can be classified in four groups, as shown in the table below. Typical applications of each group are also described in the table. Sometimes local is classified as within the building coverage and it is used as a substitute for WiFi. The outdoor PLC is also termed as Broadband on Power Line (BPL), which has both high speed and low speed versions. BPL signals also radiate Radio Frequencies (RF) less than 80 MHz. Power lines have very noisy environment and BPL devices should be designed to work in this condition. BPL equipment may also cause interference to amateur radio operators, civil aviation communication equipments, and medical equipments. Mitigation techniques for these interference problems are available.

**Table 1: Typical PLC systems**

Typical range	Low speed (64 kbps and less)	High speed (above 64 kbps)
<b>Local: less than 1000 ft</b> , only in low voltage lines (120 to 480 V)	Local residential and commercial home automation, building monitoring and control	Home office data networking, in-building audio distribution
<b>Long range: up to 40 miles</b> (to	Utility applications: meter reading, load control, operation of	Video, telephone and Internet

reach utility substation)	distribution network	services
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AMI applications use in general the low speed-long range or high speed-local range PLC groups.

### 3.1.2 Main providers and products

Some providers and products showing significant presence in global markets are:

- ACLARA: TWACS system
- LANDYS & GYR: TS1 & TS2 HUNT system
- CANON: EMETCON system
- ECHELON: NES system
- QUADLOGIC: QLC system

Annex 1 includes a detailed description of the main features and functionality of those systems. All of them have been successfully tested in AMI systems.

## 3.2 **Radio frequency**

Radio Frequency (RF) techniques use the airspace for signal transmission. Airspace is shared by many broadcast frequencies and the rights of use are issued and monitored by a national entity. However, in some countries clandestine use of unregulated frequencies is usual, creating high risk of interferences in signal transmission. RF fixed networks consist of main nodes equipped with antennas serving as repeaters. In some cases intelligent software is installed in the nodes. In some technologies, the main nodes can serve as data hubs (concentrators). Usually they operate in the ultra-high frequency (UHF)<sup>2</sup> range (frequencies between 450 MHz and 960 MHz). Most systems operate in the 2.4- 2.4835 GHz and 5.725-5.875 GHz bands; 902 MHz-928 MHz band is used only in the Americas and some Pacific Islands (defined as Region 2 by International Telecom Union). These frequency bands are called Industrial, Scientific, and Medical (ISM) bands. The transmitted power is limited to ensure that they don't cause interference to other telecommunication equipments operating in these frequency ranges. Subject to transmitter power regulations, the users are free to use these frequencies, which show in general good

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<sup>2</sup> UHF. Ultra High Frequency. It is a band of electromagnetic spectrum in the range between 300Mhz and 3 GHz frequency in what is considered short-wave systems. Its initial use is the television, where channels ranked among the 470MHz and 862 MHz. Today is the frequency used for mobile communication systems known as GSM (Groupe Special Mobile) that use of frequencies between 860 Mhz, 960 Mhz and 1800 Mhz. Wireless phones and many other commercial applications use this frequency, which is usually for public use and free.

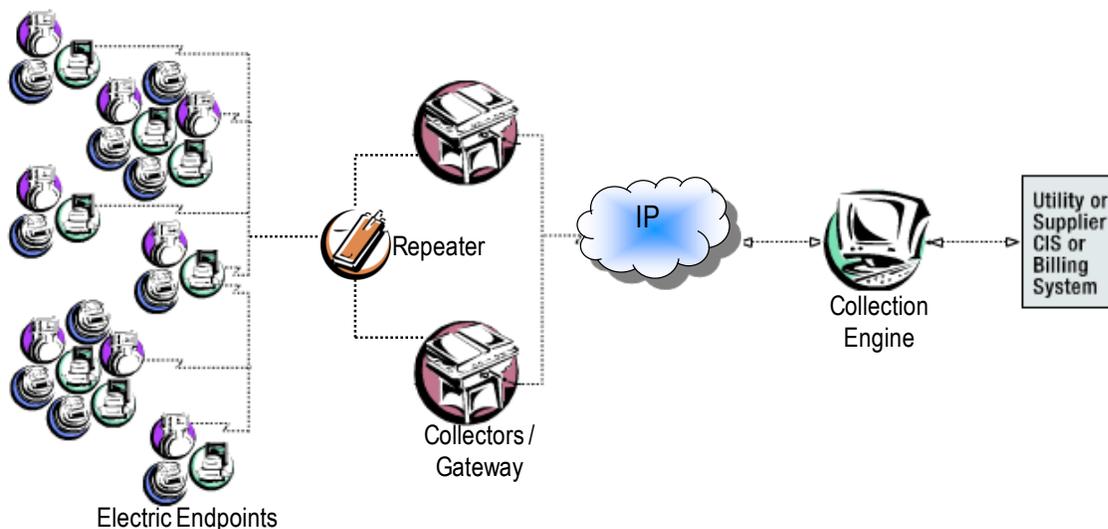
propagation and adequate coverage, and are not too sensitive to the effective existence of a "line of sight" (that means, the lack of physical obstacles between the endpoints of the communication circuit).

RF systems available in the market can be classified in two main groups:

- Long range (RF - long range)
- Mesh (RF-Mesh)

Long range RF systems use hubs or concentrators that receive data from the communication devices in the meters (AMCD). Communication can be one-way or two-way. They were initially applied in the "drive-by" systems described in Section 2. In a second stage they were used in fixed networks. Main providers and products available in the market are:

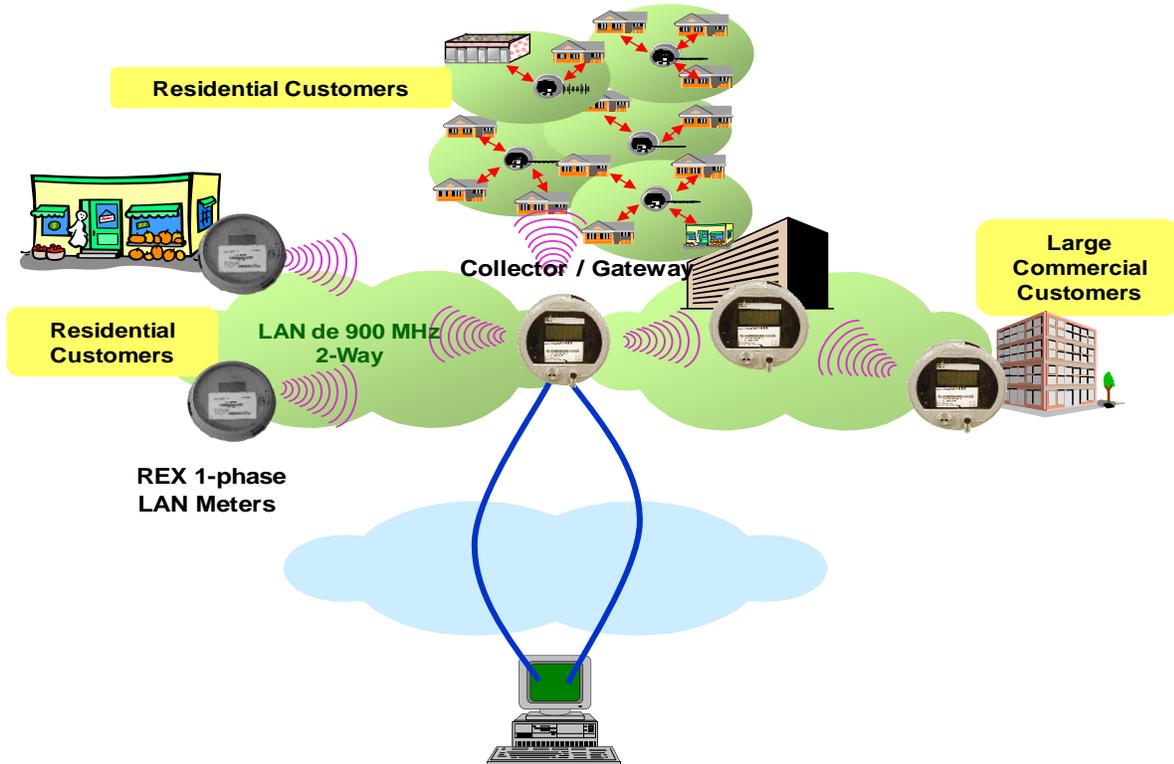
- ITRON: R300/R900 and fixed network systems.
- SENSUS: MXU and fixed net technology
- LANDYS & GYR: AIRPOINT
- TRILLIANT: WIRELESS TECHNOLOGY



**Figure 3.3: Radio frequency (RF) long range system**

As long range RF systems may be difficult to expand with good signal quality under certain topographies, geographical extent and / or lack of "line of sight", some manufacturers decided to develop a new type of network, in which each node can operate both as a receiver and transmitter (one function at each time). This makes possible to expand the geographic scope of an RF system and reduce cases of "lack of line of sight." This is the concept of the RF-Mesh. AMI also may use other wireless technologies like cellular mobile, WiFi, WiMAX, Zigbee. Main providers and products are:

- CELLNET: UTILITINET.
- ELSTER: ENERGY AXIS
- TRILLIANT: NCZ
- ITRON: WAY OPEN



**Figure 3.4: Radio frequency (RF) Mesh system**

As in the case of PLC systems, Annex 1 includes a detailed description of the main features and functionality of the RF options. All of them have been successfully tested in AMI systems.

The adequacy of each type of PLC and RF system to specific case is analyzed from a functional perspective in Section 4

### 3.3. The AMR/AMI global market

Following Table 2 summarizes main vendors, type of communication technology used and brand name, type of communication (one or two-way), and number of endpoints installed (end 2009 figures). Mobile could be two-way communication also depending upon the requirement.

<b>AMR/AMI Sort By Architecture</b>				
<b>VENDOR</b>	<b>Technology Name</b>	<b>Technology Type</b>	<b>Communication Type</b>	<b>Installed End Point Aprox.</b>
<b>ECHELON</b>	NES	PLC	Two Way	32,000,000
<b>ITRON</b>	Itron ERT (R300/R900)	Mobile	One Way	20,000,000
<b>ACLARA</b>	TWACS	PLC	Two Way	14,000,000
<b>ITRON</b>	Itron Fixed Networks	RF Fixed	One Way	13,000,000
<b>LANDYS</b>	CellNet	RF MESH	Two Way	9,000,000
<b>LANDYS</b>	Hunt TS1	PLC	One Way	4,300,000
<b>ELSTER</b>	EnergyAxis	RF MESH	Two Way	2,000,000
<b>LANDYS</b>	Hunt Airpoint	RF Fixed	One Way	1,750,000
<b>LANDYS</b>	Hunt TS2	PLC	Two Way	1,700,000
<b>SENSUS</b>	Sensus Flexnet	RF Fixed	Two Way	1,500,000
<b>CANNON</b>	Cannon	PLC	Two Way	1,200,000
<b>TRILLIANT</b>	Trilliant Wireless	RF	Two Way	1,000,000
<b>ITRON</b>	ITRON Open Way	RF Mesh	Two Way	200,000
<b>TRILLIANT</b>	Trilliant Telephone	Celular	Two Way	200,000
<b>SMARTSYNCH</b>	SmartSynch	Celular	Two Way	115,000
<b>ACLARA</b>	Star	RF Fixed	Two Way	100,000
<b>SILVER SPRING</b>	Silver Spring Ntwks	RF FIXED	Two Way	90,000

**Table 2: AMR/AMI projects implemented worldwide**

Until the end of 2009 more than 12,000 AMR projects around the world have been implemented or announced. Most of them should not be considered AMI systems, as they are using just one-way communication Power Lines Carrier (PLC) or Radio Frequency (RF) systems. The main objective of most of those projects is to collect meter reads for billing purposes.

245 AMI projects have been recently announced by public service companies worldwide. The total number of remotely metered endpoints reaches 631 million. The number of electricity companies that have announced AMI projects is 177, totaling 569,600,000 endpoints. Only 73 projects (122 million endpoints) have defined the communications technology to be applied. Following Table 3 shows the allocation of systems per technology and region in the world.

Region	Projects Announced	Total Point Announced	With Comm. Selected	Total End Point To Communicate	PLC		RF Long Range		RF MESH		OTROS	
					Total Projects	Total Points						
Norteamerica	117	54,000,000	40	36,000,000	14	11,000,000	14	11,500,000	10	7,200,000	4	6,300,000
SurAmerica	6	63,000,000	4	453,600	1	33,600	0		0		1	420,000
Central America	8	2,400,000	5	2,400,000	3	1,500,000	1	500,000	1	400,000		
Europa	36	135,000,000	21	81,700,000	16	81,000,000	1	250,000	1	250,000	3	200,000
Asia	8	315,000,000	2	1,335,000	0	0	0		1	1,300,000	1	35,000
Africa	2	200,000	1	120,000	0	0	0		1	120,000		
Totales	177	569,600,000	73	122,008,600	34	93,533,600	16	12,250,000	14	9,270,000	9	6,955,000

**Table 3: Allocation of announced AMR/AMI systems in electricity companies per technology and region in the world.**

Only 58 of the 73 projects with defined technology have been completely implemented or are at advanced stages. They involve 47,067,000 endpoints. Following table 4 shows the allocation of systems per technology and region in the world.

Region	Projects Announced	Project Installed	Total End Point Installed	PLC		RF Long Range		RF MESH		OTROS	
				Total Projects	Total Points						
Norteamerica	117	33	13,500,000	14	7,000,000	11	3,500,000	5	2,500,000	3	500,000
SurAmerica	6	4	30,000	1	14,000	0		0		1	30,000
Central America	8	5	1,800,000	3	1,300,000	1	400,000	1	100,000		
Europa	36	15	31,500,000	10	31,000,000	1	200,000	1	200,000	3	500,000
Asia	8	0	117,000					0	0	0	
Africa	2	1	120,000					1	120,000		
Totales	177	58	47,067,000	28	39,314,000	13	4,100,000	8	2,920,000	7	1,030,000

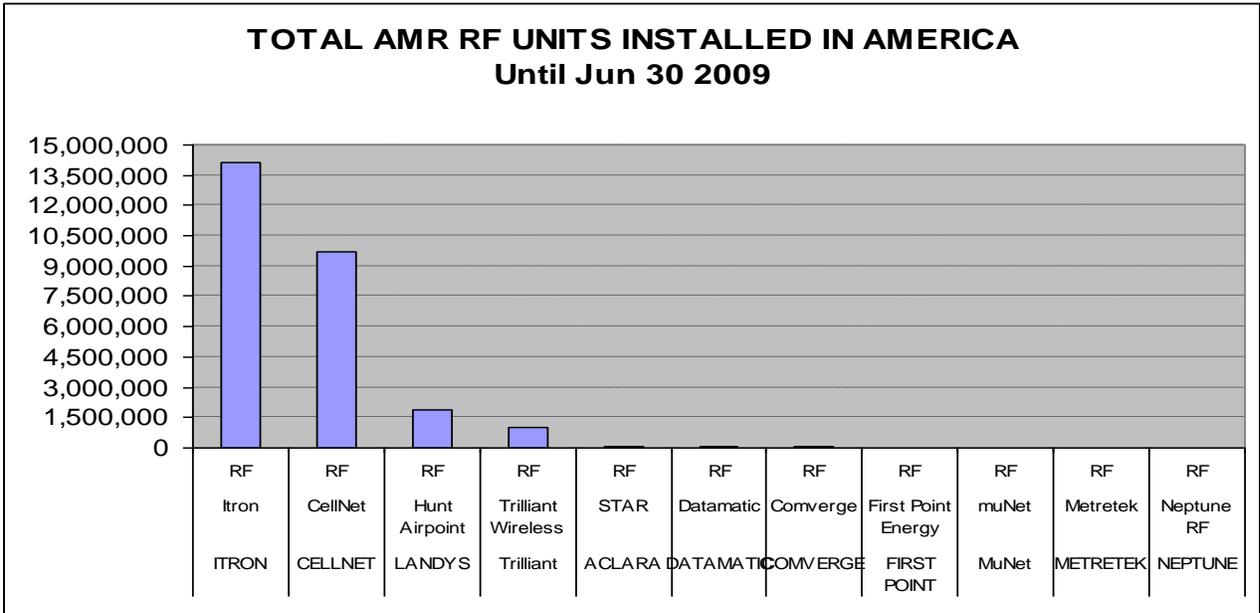
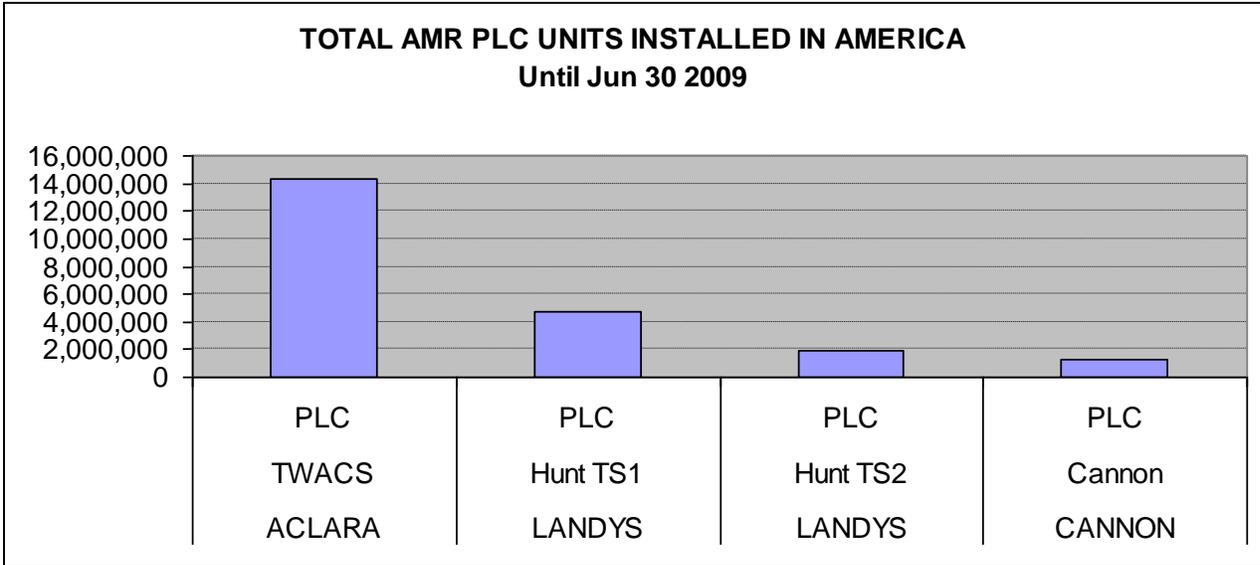
**Table 4: Allocation of AMR/AMI systems under development in electricity companies per technology and region in the world.**

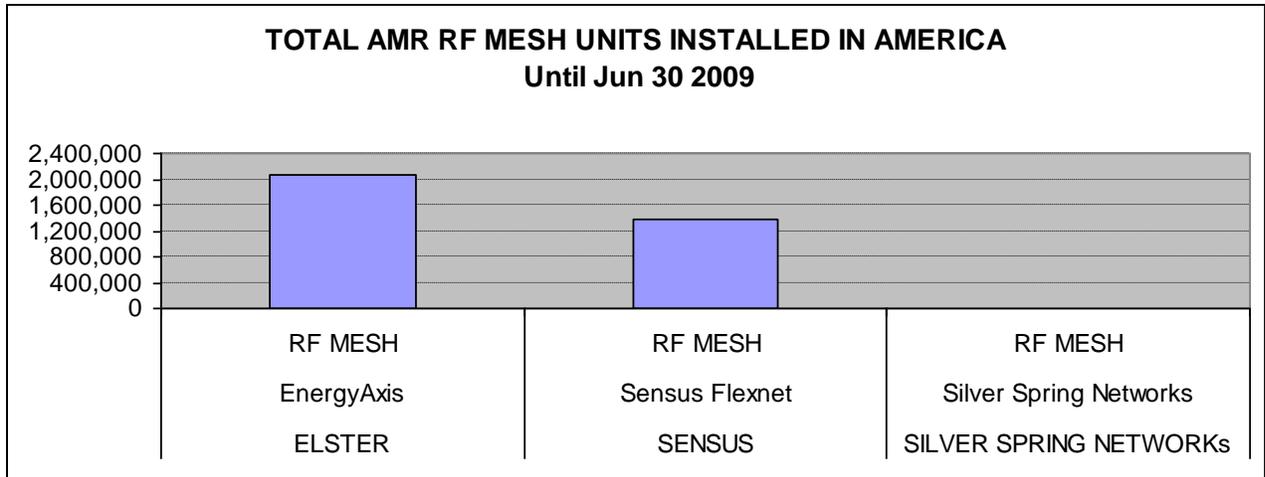
In North America (United States and Canada) around 73.5 million endpoints with AMR/AMI technology have been installed in electric utilities by mid 2009. Around 25 million of them use Drive-By technology, while other 25 million use one-way communication technology. Other 25 million use two-way communications, but only 13.5 million have been installed under an AMI approach. Table 5 shows allocation per vendor and technology.

VENDOR	TECHNOLOGY	COMMUNICATION TYPE	UNITS
ITRON	ITRON Electric Metering	Drive-By	19,473,298
ACLARA	TWACS	PLC	14,375,511
ITRON	Itron	RF	14,154,801
CELLNET	CellNet	RF	9,735,965
LANDYS	Hunt TS1	PLC	4,706,533
ELSTER	EnergyAxis	RF MESH	2,062,227
LANDYS	Hunt Airpoint	RF	1,908,559
LANDYS	Hunt TS2	PLC	1,867,661
SENSUS	Sensus Flexnet	RF MESH	1,371,928
CANNON	Cannon	PLC	1,276,182
Trilliant	Trilliant Wireless	RF	1,046,098
Trilliant	Trilliant Telephone	GPRS/TELEPHO	216,068
SMARTSYNC	SmartSynch	GPRS/TELEPHO	126,603
ACLARA	STAR	RF	107,162
DATAMATIC	Datamatic	RF	63,283
COMVERGE	Comverge	RF	38,767
FIRST POINT ENERGY	First Point Energy	RF	31,983
MuNet	muNet	RF	29,208
METRETEK	Metretek	RF	13,470
SILVER SPRING NETWORKS	Silver Spring Networks	RF MESH	4,871
NEPTUNE	Neptune RF	RF	4,428
OTHERS	Others		936,373
Totals:			<b>73,550,977</b>

**Table 5: AMR/AMI projects already implemented by electricity companies in North America**

Following figures show allocation of AMR/AMI projects in North America per type of communication technology and vendor.





#### 4. Key aspects to consider for evaluation of performance of AMI systems

The performance of an AMI system and its adequacy to provide a determined service in a specific area can be evaluated through the analysis of a set of key aspects. Some of them are described in this section.

- Architecture and technological infrastructure
- Adaptability to field topography of the served area
- Adaptability to the operational condition of customers' connections
- Adaptability to environmental conditions
- Adaptability to operational condition of the electricity network
- Adaptability to network length
- Adaptability to the type of distribution transformers (low or high capacity)
- Information transmission capacity and operational reliability
- Maintenance complexity
- Information security/Recovery systems
- Ability to identify faults in the communication system
- Installation
- Compatibility with most meters in the market
- Ability to operate equipment in the distribution network
- Cost per installed unit
- Maintenance costs
- Experience in application of the technology

An analysis of the performance of each type of AMI system regarding each of these key aspects is presented in Annex 2. Following Table 2 presents a summary of the contents of the contents and outcomes of that analysis for five of the most widely applied technological options.

<b>SYSTEM TYPE</b>	<b>PLC HIGH FREQUENCY LOW RANGE</b>	<b>PLC MED FREQUENCY HIGH RANGE</b>	<b>PLC LOW FREQUENCY HIGH RANGE</b>	<b>RF LONG DISTANCE</b>	<b>RF SYSTEM MESH</b>
<b>TOP VENDORS</b>	<b>ECHELON QUAD LOGIC</b>	<b>CANON</b>	<b>ACLARA LANDYS&amp;GYR</b>	<b>SENSUS TRILLIANT</b>	<b>ITRON ELSTER CELLNET</b>
<b>Technical/Functional Feature</b>					
<b>Architecture and technological infrastructure</b>	<b>Solid</b>	<b>Solid</b>	<b>Very Solid</b>	<b>Very Solid</b>	<b>Solid</b>
	- PLC systems operating in medium and high frequencies in general require the installation of specific equipment (repeaters or bridges) to allow the signal to pass from low voltage to medium voltage networks. This increases their vulnerability.				
	- Radio frequency systems and low voltage PLC systems in general require a large number of concentrators, which makes network infrastructure more extended and vulnerable.				
	- Infrastructure of the low frequency PLC systems operating in low and medium voltage is simple and less vulnerable, as the communication equipment is located in substations operated by the electricity company.				
<b>Adaptability to field topography of the served area</b>	<b>Good</b>	<b>Very good</b>	<b>Very good</b>	<b>Fair</b>	<b>Good</b>
	- In general PLC technologies are the most effective in service areas with sparsely located consumers (low density) and/or very steep terrain, except that only low voltage work				
- RF technologies may not be an adequate option when "lines of sight" are hard to be set or jumps for the communication links are large. RF mesh technology partially solves this problem as each meter can operate as a receiver and transmitter, reducing the cases of lack of "line of sight" and reading failures in the system.					
<b>Adaptability to the operational condition of customers' connections</b>	<b>Very good</b>	<b>Very good</b>	<b>Very good</b>	<b>Fair</b>	<b>Good</b>
	- Many projects for reduction of non-technical losses include installation of meters in armored panels to avoid access to them by consumers and external agents. In some countries there are no manufacturing standards for the installation of metering equipment. They are located on basements, under stairs or in areas with poor conditions for transmission of a RF signal. Use of RF technologies may imply increased investment costs if it becomes necessary to install antennas or repeaters to amplify the signal.				
	- PLC technologies are fully insensitive to the location of meters and work adequately in any condition.				
<b>Adaptability to environmental conditions</b>	<b>Very good</b>	<b>Very good</b>	<b>Very good</b>	<b>Good</b>	<b>Good</b>
	- Systems with low amounts of components installed on the network are less exposed to weather conditions and their impacts.				
- If RF techniques are used, it is crucial to verify the condition of the radio spectrum in the frequency range in which they will operate. Eventual existence of clandestine bands that could affect signal transmission must be checked. It is also important to check existing licensing and monitoring procedures for allocation of use of communication bands and their effective enforcement (potentially a major problem in countries facing governance weaknesses).					
<b>Adaptability to operational condition of the electricity network</b>	<b>Fair</b>	<b>Good</b>	<b>Good</b>	<b>Very good</b>	<b>Very good</b>
	- Operational condition of the electric network can affect quality and reliability of signal transmission in some PLC systems, especially those operating in medium and high frequency. The low-frequency systems are less sensitive to network conditions, although some specific electromagnetic effects (harmonics) may affect their performance.				

SYSTEM TYPE	PLC HIGH FREQUENCY LOW RANGE	PLC MED FREQUENCY HIGH RANGE	PLC LOW FREQUENCY HIGH RANGE	RF LONG DISTANCE	RF SYSTEM MESH
TOP VENDORS	EHELON	CANON	ACLARA	SENSUS	ITRON
	QUAD LOGIC		LANDYS&GYR	TRILLIANT	ELSTER
					CELLNET
<b>Technical/Functional Feature</b>					
Adaptability to network length	Fair	Good	Very good	Good	Good
	- Long networks can affect performance of some PLC systems operating in medium and high frequency. Installation of relays and amplifiers may be required to ensure adequate signal transmission.				
	- If RF systems are used, long networks could imply a low number of meters per hub and big amounts of WAN communications links, repeaters or antennas. This affects both investments costs and overall reliability				
Adaptability to the type of distribution transformers (low or high capacity)	Low	Fair	High	High	High
	- Use of small capacity transformers affects performance of PLC systems that require installation of a bridge to pass signals from low voltage lines to medium voltage lines. For those that only operate over low voltage lines and require a hub and a line of communication per each processor-hub the implementation and maintenance costs will be high.				
Capacity to transmit information and operational reliability	Well Reliability and Very Good Capacity	Well Reliability and Capacity	Very Good Reliability and Well Capacity	Well Reliability and Very Good Capacity	Well Reliability and Very Good Capacity
	- Capacity to handle information of RF systems is higher than that of PLC systems operating in middle and low frequency. However, the largest systems currently in operation (millions of connected points) use PLC technology.				
	- Reliability is in general higher in PLC systems, as they are less exposed to external sources of interference.				
Maintenance complexity	Fair	Fair	Very low	Fair	Fair
	- In general maintenance of PLC systems is easier, as the electricity distribution network is also the communication network.				
	- A failure in power supply to the customers becomes a failure in the communication link.				
	- Improvements in quality of distribution network will also have a positive effect on performance of the communications system.				
	- Long range PLC systems (low frequency-high range) have their equipment located in the distribution substations, making maintenance activities easy to carry out.				
	- RF systems require continuous maintenance of equipment installed on the network for various reasons such as blockages generated in the "lines of sight", large number of concentrators and communication links that must be installed to collect data, etc. Cost of maintenance of RF systems is around 4 times that of equivalent (same service level) PLC systems.				

SYSTEM TYPE	PLC HIGH	PLC MEDIUM	PLC LOW	RF LONG DISTANCE	RF MESH
	FREQUENCY		FREQUENCY HIGH RANGE		
	LOW RANGE				
TOP VENDORS	ECHELON QUAD LOGIC	CANON	ACLARA LANDYS&GYR	SENSUS TRILLIANT	ITRON ELSTER CELLNET
<b>Technical/Functional Feature</b>					
Information security/Recovery systems	Good/Very good	Good/Very good	Very good/Very good	Good/Very good	Good/Fair
	- RF technologies and protocols are more popular and quite well known by the general public. This implies higher risk of intervention by external agents, as the signal travels through airspace.				
	- Protection against external interference is important. But it is even more critical the actual capacity of the system to recover and reconfigure itself after faults. RF systems, especially of the “Mesh” type, rank poorly in this criterion. A failure in power supply can affect a large number of repeating points and hubs and oblige to restore the network, a process that could take hours. Proper consideration of this aspect is crucial in countries where quality of electricity supply is bad and scheduled or forced outages are frequent.				
Ability to identify faults in the communication system	Good	Very good	Very good	Good	Fair
	- In RF systems, especially those of the “mesh” type, it is difficult to determine the origin of a failure. Without a connection between a hub and a meter, it is quite hard to determine if the failure is the consequence of a blocked channel, equipment malfunction, or a power outage. The company may be obliged to perform several review visits before being able to identify the cause of a failure.				
Installation	Simple	Simple	Very simple	Simple	Simple
	- RF systems require a more comprehensive and detailed planning of network design. A precise diagram ensuring good coverage and redundancy must be elaborated, taking into consideration location of meters, topography constraints, condition of the radio spectrum, etc.				
	- Design is not an issue for PLC systems because the electricity network is used for communications.				
Compatibility with most meters in the market	High	Very high	Very high	Very high	Very high
	- Most of AMI systems currently available in the market can incorporate meters from a wide number of manufacturers. Although there are still some very limited platforms, most of them have evolved towards the elimination of constraints regarding the incorporation of metering equipment				
Ability to operate equipment in distribution lines	Low	Low	Medium	High	High
	- RF systems and PLC systems operating over the medium and low voltage lines provide great capabilities to operate equipment in the distribution networks.				
	- PLC systems operating only over low voltage lines show very limited capabilities to operate distribution equipment.				

SYSTEM TYPE	PLC HIGH	PLC MEDIUM	PLC LOW FREQUENCY	RF LONG DISTANCE	RF MESH
	FREQUENCY LOW RANGE	FREQUENCY HIGH RANGE	HIGH RANGE		
TOP VENDORS	ECHELON	CANON	ACLARA	SENSUS	ITRON
	QUAD LOGIC		LANDYS & GYR	TRILLIANT	ELSTER
					CELLNET
Others Features					
Cost per installed point	Average	Average	Low	Average	High
	- PLC systems, especially those operating in low frequency and not requiring specific equipment to allow the signal to jump from low to medium voltage lines, have a lower cost per installed user. The expansion cost is also the lowest.				
	- RF systems investment costs vary significantly depending on the final design of the network. The addition of new meters is usually more expensive than in the case of PLC systems. Within the RF technology, “Mesh” systems tend to have a slightly higher cost, justified by the ability of each meter to work as a transmitter, a receiver and a repeater.				
Maintenance costs	High	Low	Very Low	Average	Average
	- Maintenance costs of low frequency PLC systems is lower due to:				
	o They require less remote connection points to be communicated using services provided by the telephone company				
	o They require less operational effort in maintenance of communication links				
Experience in application of the technology	High	Average	High	High	Average
	- Both PLC and RF technologies have evolved through a process of settlement and development. PLC and long range RF technologies have been in the market for more time than RF “Mesh”.				
	- AMI systems with larger amounts of connected points or readings use PLC technology. Nevertheless, systems that use RF technology are more numerous.				

## 5. Application of AMI systems in electricity companies in World Bank country clients

### 5.1 Sustainable reduction of non-technical losses and protection of revenues

#### 5.1.1 The crucial need to reduce non-technical losses

In electricity supply to final consumers, losses refer to the amounts of electricity injected into the transmission and distribution grids that are not paid for by users.<sup>3</sup> Total losses have two components:

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<sup>3</sup> Customers are those consumers who have a commercial relationship with the electricity supplier within the applicable regulatory framework. Users of electricity, on the other hand, include customers as well as those who are not customers but nevertheless consume electricity through theft or by unofficial diversion from another customer.

technical and non-technical. Technical losses occur naturally and consist mainly of power dissipation in electricity system components such as transmission and distribution lines, transformers, and measurement systems. Non-technical losses are caused by actions external to the power system and consist primarily of electricity theft and other ways of unmetered consumption. They are sometimes referred to as commercial losses.

Optimization of technical losses in electricity transmission and distribution grids is an engineering issue, involving classic tools of power systems planning and modeling. The driving criterion is minimization of the net present value (sum of costs over the economic life of the system discounted at a representative rate of return for the business) of the total investment cost of the transmission and distribution system plus the total cost of technical losses. Technical losses are valued at generation costs.

Technical losses represent an economic loss for the country, and its optimization should be performed from a country's perspective, regardless of the institutional organization of the sector and ownership of operating electricity utilities. Although each case has its specific characteristics, depending on the current and future values of generation costs, some general comments can be made. Energy experts agree that, in the next two decades, global prices of primary energy resources (oil and other fossil fuels) will steadily increase in real terms. On the investment side, prices of equipment in the electricity sector (generation, transmission and distribution) steadily rose this decade until the global financial crisis that began in the 3<sup>rd</sup> quarter of 2008. Against these price trends, the total costs of technical losses tend to exceed investment costs of transmission and distribution equipment required to reduce them to their optimum value, more so where a significant portion of generation is based on fossil fuels. This tendency is accentuated if environmental costs of power generation (harmful local pollutants as well as greenhouse gas emissions) and increasing difficulties in achieving social acceptance of new power plant construction (regardless of fuel type and technology) are taken into account.

Non-technical losses represent an avoidable financial loss for the distribution company, as it is evident that metering and billing for electricity actually consumed by users is integral to commercial management of an electricity utility.

Although it is clear that the amounts of electricity involved in non-technical losses are being consumed by users that do not pay for them, experience shows that a significant percentage of those amounts (in some cases more than 50 percent) becomes reduced demand when those users have to pay for that electricity, because they adjust their consumption to their ability to pay for electricity services (see Reference 1). That reduction in demand has exactly the same effect as a reduction in technical losses: less electricity needs to be generated. Thus, from the country's perspective, reductions in non-technical losses are also positive.

From a social point of view, non-technical losses have several perverse effects. Customers being billed for accurately measured consumption and regularly paying their bills are subsidizing those users who do

not pay for electricity consumption. There is a wide range of situations creating non-technical losses. A classic case is a theft of electricity through an illegal connection to the grid or tampering of a consumption meter. But examples also include unmetered consumption by utility customers who are not accurately metered for a variety of reasons. In all the cases some level of poor management of the utility in execution of its operations is present.

Electricity theft is de facto subsidization of those who steal by customers regularly paying bills according to their consumption. The same usually applies in the case of unmetered customers, unless this situation is explicitly and transparently defined by the competent authorities and reflected in the legal and regulatory framework of the sector—in some countries some categories of consumers (e.g., agriculture users in India and Bangladesh) are unmetered and pay a fixed amount for electricity service (based in general on some parameter representative of installed demand) irrespective of the amounts consumed, which means in practice that they are subsidized by consumers in other categories, tax payers, or both. Depending on the financial situation of the power sector, the savings from reductions in non-technical losses could be channeled to a) reduce tax-payers subsidies or tariffs paid by customers, b) achieve an average tariff level allowing recovery of costs reflecting efficient sustainable performance (critical to assure service quality), c) subsidize consumption of selected categories of socially sensitive existing users, or d) extend access to electricity supply to currently unserved population (in general the poorest and socially unprotected).

Non-technical losses in the power sector are almost non-existent or negligibly small in developed countries, as most of the population can afford to pay tariffs reflecting costs of supply (even if they are higher than those reflecting optimized performance of the service providers). In contrast, although mixed, the situation tends to be significantly different in developing countries. Many electricity utilities in developing countries succeeded in significantly reducing or eliminating non-technical losses in electricity supply on a sustainable manner, but others continue to show high losses. Theft and fraud in electricity distribution continues to jeopardize the sustainability of the whole power sector of several low-income developing countries worldwide, as well as that of companies serving the poorest regions in middle income developing countries.

In all successful cases of reduction of non-technical losses in developing countries, a large share of those losses was concentrated in users able to pay for cost-reflective tariffs. Thus, non-technical losses can be reduced with little loss of welfare, while their continuation puts at risk the financial sustainability of the power sector and harms well-behaving-electricity consumers, taxpayers, socially disadvantaged segments, and the country as a whole. Elimination of those losses (with the exception unmetered consumption explicitly and transparently defined in the regulatory framework) should be a matter of high national priority for every country.

#### 5.1.2 How application of AMI can help to achieve a sustainable reduction of non-technical losses

Market served by electricity companies is in general characterized by the presence of the “Pareto or ABC effect”. Namely, a small group of large consumers (usually less than 1 percent of total number of customers) supplied at high (HV) and medium voltage (MV) accounts for a big share of revenues of the company (30 percent or more). If the largest consumers supplied at low voltage (LV) are added, 3 to 5 percent of total number of customers account for 50 percent or more of total revenues. In order to ensure the financial health of the company it is of utmost importance first to permanently remove theft and fraud in electricity supply to the largest HV and MV consumers, and then gradually reach the same condition in supply to the largest consumers connected to low voltage networks. This sequencing of operations has been successfully implemented by several utilities in Latin American countries that reformed their respective power sectors in the 1990s, through a combination of good management practices and the application of ICT tools available at this time.

Although at the time of those reforms the application of remote metering systems was well known, it was still unfeasible due to high investment costs of metering equipment and limited development of communication systems. Thus, the utilities implementing successful action plans to reduce losses had to include systematic monitoring through field inspections, carried out by their best staff (in terms of technical skills and personal integrity), as a critical component to promote market discipline. This approach implies big expenditures and, more importantly, it does not ensure a sustainable solution to the problem. The case of Brazil is a clear example supporting this statement. Current total losses in the power sector reach 13.1 percent of amounts of energy injected in the electricity networks countrywide, which is a quite acceptable figure for a large developing country. However, non-technical losses increased by 23 percent from 2006 to 2009 and currently represent 5.8 percent of injected energy (23,300 GWh/year)<sup>4</sup>. Valuing them at the average retail tariff (US\$ 150/MWh), this represents a financial loss for the distribution companies of US\$ 3.5 billion per year. Assuming that half of the total amount of non-technical losses is eliminated and becomes reduced demand, the economic benefit for the country will exceed US\$ 1 billion per year (considering the US\$ 90/MWh expansion cost resulting from studies carried out by EPE, the government agency responsible for power sector planning).

While the fundamentals concerning the legal and institutional aspects of the successful initiatives implemented in several developing countries in the 1990s remain fully valid, reengineering of business processes must be dynamic and continually adapt to technological evolution, particularly with respect to ICT and, more specifically to AMI.

Large-scale application of AMI, starting with large consumers and gradually extending to medium and small ones, is an extremely effective tool to detect and discourage theft and other ways of unmetered consumption, as shown by the recent experience in developing countries. It has the following positive impacts (in general significant in countries where levels of corruption are significant):

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<sup>4</sup> Presentation by the Brazilian electricity regulator ANEEL in Brasilia on February 04, 2010, available at: [www.seminarioautomacaoeletrobras.com](http://www.seminarioautomacaoeletrobras.com).

- “Watchdog” effect on users. Users become aware that the utility can monitor consumption at its convenience. This allows the company fast detection of any abnormal consumption due to tampering or by-passing of a meter and enables it to take corrective action. The result is consumer discipline. This has been shown to be extremely effective with all categories of large and medium consumers having a history of stealing electricity. They stop stealing once they become aware that the utility has the means to detect and record it. Recent experience in Brazil, Dominican Republic, Honduras and India shows that consumers stop stealing if they face the risk of social condemnation. More importantly, they do not go back to stealing electricity.

- Enhancement of the company’s corporate governance and anti-corruption efforts. Instances of theft by large consumers usually involve collusion between them and the meter readers (the bottom of a pyramid within the utility that can reach high management levels). AMI eliminates the need for regular field operations (such as meter readings and service disconnections), thus greatly improving governance and reducing room for corruption. Deployment and use of AMI also makes information about consumption transparently and timely available to both the clients connected to the system and the management of the utility (at all levels). Any abnormal change in consumption patterns due to tampering or by-passing of a meter can be detected, enabling the utility to take immediate corrective actions. This provides discipline for consumers prone to theft and fraud to change behavior, stopping tampering meters and stealing, because of threat of being detected and punished.

### 5.1.3 Phased approach for implementation of an AMI system

#### 5.1.3.1 The case of large medium and high-voltage consumers

Implementation of an automated metering project must always start with the medium and high voltage consumers. As already mentioned, they are usually less than 1 percent of total number of customers but account for at big share of revenues of the company (30 percent or more). The financial health of the company crucially depends on protecting those revenues. For that purpose, it becomes necessary to ensure that all consumers in this group are permanently billed according to their actual consumption.

##### (a) Predominant approach

Total number of HV and MV consumers is in general low (a few thousand), and their geographic location is disperse. Thus, implementation of automated metering for this group does not require the features of a massive solution. Usually each consumption point is remotely metered, read and monitored through an individual link. Values of several parameters of electricity supply, including alarms due to any abnormal condition (meter manipulation, loss of power supply, etc.) are transferred through that link in short intervals of time (typically 15 minutes to one hour). This means that a large amount of data must be downloaded from the meters and transferred to the company’s server for analysis and monitoring. Due to

this reason, the predominant approach for communication between meters and servers is the use of the cellular network, in general applying the GSM/GPRS technology<sup>5</sup>, which is the most widely used in the world, both in developed and in developing countries, and also the cheapest. A GSM/GPRS modem is installed within the meter or externally attached to it. Sometimes power companies use All Dielectric Self Supporting (ADSS) and Optical Ground Wire (OPGW) equipments for internal power system management. In those cases, the combination of WiFi/Zigbee wireless technologies with ADSS/OPGW may provide a cost effective solution.

The main manufacturers of electricity consumption meters have developed standard products including GSM/GPRS communication modems. They also went into strategic partnership with companies providing software specifically designed to handle the data transmitted through the communication links and read them from the company's server. This software is sometimes referred as "Data Collection System (DCS)", and its purpose is to download the data from mass memory meters, usually 10, 12 or 16 channels<sup>6</sup> of information at 15 minute intervals. Most of DCS packages can be used with a wide range of consumption meters and communication systems. This gives the distribution company the chance to use existing meters and simply add external modems to them.

(b) Technical aspects to be considered

The application of cellular networks for data communication implies to take proper consideration to the following aspects, in order to ensure a quality level consistent with the importance of the information for the electricity company.

- Compatibility of the local cellular network with the communication equipment to be installed at each metering point must be checked, as there are several options in cellular technologies like GSM, CDMA and PHS
- A first level team for maintenance of the communication equipment (including troubleshooting) needs to be established and kept under permanent training.
- Quality of service provided by the cellular network operators must be tested. If there are several operators in the market, it is convenient to allocate communication services among two or more of them to promote competition for a good quality service.
- The cellular network is used both for voice and data transmission. Thus, the potential risk of congestion needs to be properly assessed. Data that are not transmitted at short intervals should be

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<sup>5</sup> GSM (Group Special Mobile)/GPRS (General Packet Radio Services). GSM is a digital platform for mobile communications. GRPS is an extension of GSM technology that works with data packet. The unit of service provided is the packet of data transmitted and not the time of use of the communication channel. This technology supports a rate range from 56Kbps to 144 Kbps.

<sup>6</sup> Channels. It is the meters memory area where the different electric parameters are recorded. The number of channels depends on the type of meters. The big customers meter can drive between 16 and 32 channels.

transferred during night time, where the networks are not being used for voice communication. This also allows the electricity company to negotiate better prices for the service.

- The condition of the site where the communication device is installed must be checked. Sometimes the meters are located in areas where there is high interference and/or low network signal. This may imply the need to replace the cellular communication by private long range radio links, operating in ultra high frequency (UHF). In case there are some dark spots, where cellular coverage is not available, mobile phone operators may deploy Femto cell equipment to solve the problem. Femto cells have become regular components of cellular networks to ensure good service quality to agriculture customers in some regions in India.

(c) Investment and operating costs – Cost effectiveness of the approach

Typical market prices of internal modems for meters are in the range of US\$ 150 to US\$ 200. For an external modem the price varies from US\$ 250 to US\$ 400, depending on the type of GSM technology used by the device (GPRS, EDGE<sup>7</sup>, or 3G). The price of the DCS varies from US\$ 50,000 to US\$ 150,000. The operating costs (price paid by the distribution company for the use of the cellular network) vary from country to country, and sometimes from region to region in the same country. Currently, a typical price could be around US\$ 10 per month and per connected point. All the figures in this paragraph are provided only for illustrative purposes. Impressive developments in communication technologies, if accompanied by unrestricted competition, can create drastic changes in very short time periods.

A more expensive solution consists of duplicating or “externalizing” the metering system by installing a new one (including current and voltage metering transformers) in a fully sealed box located outside the customer’s premises. This solution is used when the customer does not allow the utility to access the existing metering system (in spite it is owned by the distribution company) to replace its components by new ones with AMI capabilities. This has occurred in certain regions of Brazil, where the justice system does not function properly. Installation of a new system outside the premises costs about US\$5,000 per point of supply. Some companies adopt this expensive solution as the basic option considering its extremely high effectiveness: experience shows it makes almost impossible to steal electricity and eliminates any chance of interference by the customer. And the cost is very low when compared to the amount of revenues permanently protected.

The rate of return of projects for automated meter reading (AMR) of high and medium voltage consumers is extremely attractive in most cases. Although it depends on average tariff levels and amounts of electricity previously stolen, some basic figures illustrate their effectiveness. A US\$ 300 to US\$ 400 cost to implement a remote metering system using existing facilities is equivalent to 3,000 to 4,000 kWh at an

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<sup>7</sup> EDGE (Enhanced Data rates for GSM Evolution) is an evolution from GPRS technology. The capacity for data transfer goes up until 384 Kbps. According to the implementation level, these communication networks can be of second generation (2G) or third generation (3G).

electricity price of US\$0.10 /kWh. In the case of a large user stealing this amount every month (not very significant for a customer with recorded consumption in the range of 10,000 to 20,000 kWh a month), the investment will be recovered in one month through billing of the previously unmetered consumption.

Even being more expensive, the solution based on “externalization” also has in general a very high rate of return, because a large customer blocking access to the metering system on his premises is most likely to be engaged in fraudulent behavior and not paying fully for electricity consumed.

(d) Barriers to overcome

Electricity supply to final consumers is a typical retail business. However, it has a “wholesale” component, which is the service provided to high and medium voltage consumers. Proper management of this segment requires the adoption of a set of specific approaches.

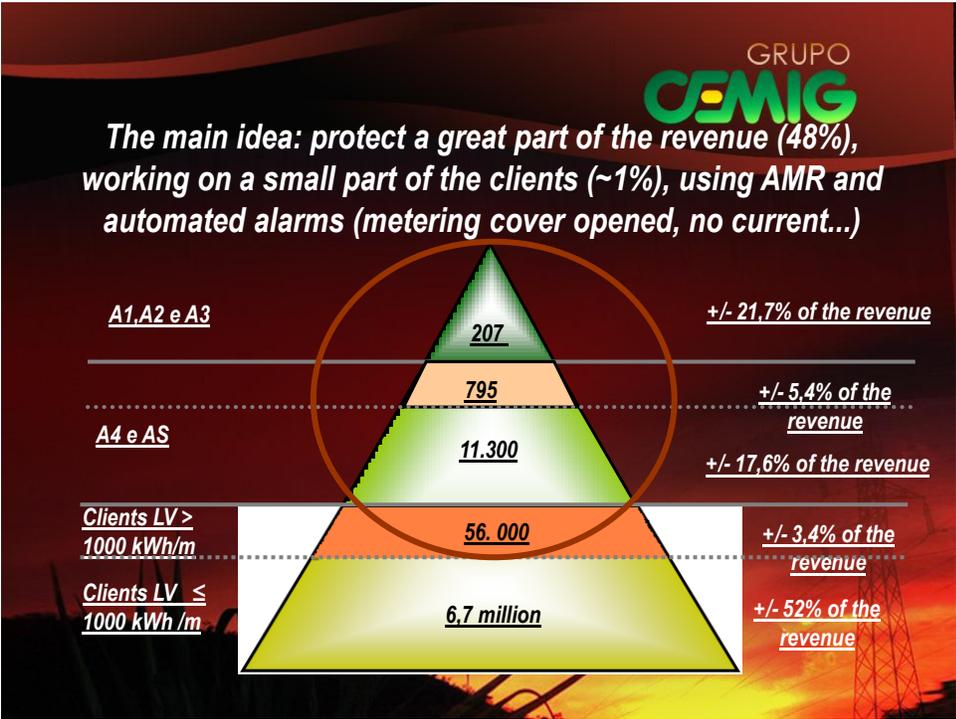
As mentioned above, successful cases in several developing countries evidence that when a distribution company has a high amount of non-technical losses, a significant share corresponds to supply to large consumers. Potential undue earnings arising from systematic under-billing of those consumers are actually enormous, and this creates incentives for collusion between customers and utility’s staff. Managing a company ignoring this circumstance is in practice equivalent to promote, or at least tolerate, the risk of those corrupt behaviors.

Experience also shows that companies that have incorporated remote metering of their high and medium voltage consumers fully eliminated non-technical losses in supply to this segment. It is a sustainable solution for protection of revenues that are critical for the company’s financial health, easy to be implemented, implying limited expenditure, and with extremely high rates of return. **In other words, there are many strong reasons to adopt it without any delay, particularly if the company is in financial distress due to high non-technical losses.**

However, it is quite usual to find utilities in developing countries facing high non-technical losses, but whose management is reluctant to implement this solution. There may be several explanations for this attitude. The less negative is the “monopolistic culture”. In some cases (particularly state-owned enterprises) nothing changes for managers if the performance of the company is good or bad, as monopolies don’t fail. Thus, they keep the “statu-quo”, and do nothing to reduce losses. In other situations, top management is directly involved in the big side-business related to systematic under-billing of large consumers. It is quite easy to identify these cases: managers will argue that supply to that segment is closely monitored by them, and they can assure there are no commercial losses (although they will not be able to provide evidence of this statement). Thus, they find unnecessary to spend money in remote metering.

There is a very strong argument to overcome reluctance to implement remote metering of the large consumers segment. Avoiding any discussion on current situation of a specific company, the great

importance of a permanent protection of revenues related to sales to that segment for the financial health of the utility justifies the adoption of approaches that ensure a sustainable elimination of non-technical losses. Sustainability is precisely the key concept supporting the implementation of remote metering of the large consumers by companies currently showing a very good performance. A paradigmatic example is the case of CEMIG, the largest electricity distribution company in Brazil, serving more than 7.2 million customers in a 500,000 km<sup>2</sup> area in the State of Minas Gerais (having the second largest gross domestic product in the country). Current operational and financial performance of the utility is superb, with 8.7 percent technical losses and 2.3 percent non-technical losses. However, in order to sustain and improve this performance, CEMIG is implementing remote metering of its largest 68,000 consumers (less than 1 percent of total number), representing 48 percent of its current revenues. Management noticed that keeping current values of non-technical losses implies a big (and increasing) effort in terms of field inspections, which is an expensive option that does not ensure sustainability of current performance. Remote metering is cheaper and makes possible a permanent protection of the revenues related to sales to large consumers. Besides, it provides full transparency in a key management issue, minimizing the risk of corruption and enhancing company's corporate governance. The Brazilian electricity regulator supports this approach and recognizes investment (depreciation plus return) and operating costs of remote metering in the company's allowed revenues, while at the same time decreases the regulatory allowance for expenditures in field inspections.



(e) Key elements for successful implementation – Lessons learnt

Several recent cases become source of relevant lessons on some key elements that must be addressed in order to ensure successful implementation of a remote metering system for large consumers (in addition to the technical aspects in paragraph (b) of this section). They refer in essence to company's management, but also include issues related to scope of the metering system.

- The distribution company should create a "Large Customer Department (LCD)", responsible for managing all aspects of its interaction with large customers (metering, billing, collection, attention of claims related to quality in electricity supply). Its manager must be an expert with wide professional experience in the commercial management of large customers. Organizational structure and operational procedures of LCD should ensure that each large consumer receives personalized attention from a single "contact person" in the company, who should be responsible for addressing all the issues in the interaction, taking care of all the internal arrangements needed for that purpose.

- A "Metering Control Center (MCC) should be created within the LCD, with the specific assignment of operating the remote metering system for large consumers. Staff of the MCC should be young engineers, trained by system provider. Their main tasks should be: (i) ensure permanent reliable and timely reception of data provided by the system; (ii) carry out systematic analysis of the data, in particular alarms, changes in daily consumption, etc.; (iii) implement corrective actions that may arise as a consequence of the analysis, such as field inspections to customers' premises by crews directly reporting to the MCC (fully independent from those involved in field inspections to other customers); (iv) follow-up of the results of the inspections; (v) permanent update of the database used by the system.

- A specific "intelligent" software, usually referred as "Meter Data Management (MDM)" must be incorporated by the company to make possible efficient performance of the MCC. Most of the providers of remote metering systems are companies based in developed countries, where the main use is for periodic (monthly or bimonthly) read of consumption for billing purposes. Thus, those systems include a very simple software package, designed to properly manage those reads. However, in general that software is completely inadequate to carry out systematic analysis of the daily consumption of a large customer and compare it with reference values, which is the key feature for timely detection and correction of abnormal situations (fraud, theft, etc.). Thus, incorporation of a software package specifically designed to make possible an efficient development of that analysis for each and all consumers in the system, presenting as alarms pre-parameterized deviations in consumption from a standard pattern, is absolutely crucial to effectively reduce non-technical losses. Some real cases show that the consequences of not incorporating the MDM can be devastating. One of the distribution utilities in Dominican Republic implemented in 2006 remote metering of its large consumers, applying one of the state-of-art PLC technologies provided by a company in the United States. This made possible a sustained reduction of total losses from 38 percent in 2006 to 30 percent in 2008. Although the system provides daily reads of all the meters, the standard software package attached to it is designed to handle monthly reads for billing purposes. And this is the only feature being actually applied by the utility. All the daily reads provided by the remote metering system are stored in a database but nobody analyzes them. In other

words, the system is not being used for the main purpose justifying its incorporation: an effective detection and elimination of non-technical losses. Not surprisingly, the case was recently detected by supervisors in the holding company, as it didn't seem to be a problem for the managers of the distribution company. Corrective actions to restore full application of the remote metering system functionality are currently being implemented.

- Organizational arrangements for proper maintenance of all the components of the AMI system and ensure its sustainable good performance need to be defined and implemented. An approach that is becoming widely used by several companies in developing countries includes contracting the supply, installation, commissioning and maintenance of all the components (hardware and software) of the AMI system during a 2 to 5 year period with a special purpose group, formed by companies providing skills in meter manufacturing and installation and MDM software. It is based on considering AMI as the provision of metering services that are crucial for the good performance of the electricity utility, but not part of its core business (which is the provision of electricity services to its customers meeting the standards on service quality and billing and collecting the actually supplied amounts). Under this approach, all the field activities related to installation and maintenance of the components of the AMI system are outsourced to the contractor, who becomes fully responsible for their proper performance. The electricity company retains for itself the actually core functions of processing all the data provided by the AMI system, which include billing, detection and correction of any abnormal condition, load management, planning, etc. Allocation of overall responsibility for the good performance of the AMI system to a single contractor clearly helps to ensure its sustainable operation, minimizing the risks of outages due to failures in some of its components. As already stated, cases of high non-technical losses usually involve intentional systematic under-billing of large consumers as an undue source of big revenues for some utility staff. As AMI eliminates this side-business, that staff could try to impede the effective implementation of the system. Some recent experience includes cases of damage to meters (direct sabotage) and others of failures in communication components that are not repaired and “oblige” the utility to continue using the manual reading at customer's premises.

#### 5.1.3.2 Expansion to medium and large low-voltage consumers

##### (a) Criteria to define expanded scope

In some companies remote metering programs are limited to the high and medium voltage consumers. However, as implementation costs continue to decrease, a broader scope is becoming predominant in developing countries to ensure that the greatest possible sustainable reduction of non-technical losses is actually achieved. All the low voltage customers with contracted demand or monthly energy consumption above a certain threshold are included in the program. Typical values are 10 kW demand and 500-1000 kWh/month, although there are wide variations from case to case. The decision on the threshold for a specific case requires an in-depth analysis of the composition of the market (number of customers in each consumption interval), average tariff, etc. The concept supporting this expansion based on individual

consumption is exactly the same applied for large high and medium voltage customers: sustainable protection of revenues generated by supply to a small group of users that represent a large share of total sales, ensuring the inexistence of non-technical losses.

Some companies adopt a slightly different approach. Implementation of AMI to low voltage consumers is driven by consumption per customer combined with geographic location. The zones showing the largest values of amount of injected energy/customer are identified and AMI is implemented to each and all of the customers connected to a same distribution transformer (DT) and to the LT terminal of the transformer (to monitor energy flowing through it). This is a more expensive option, as all consumers supplied by a same transformer are included in the AMI program, regardless of their consumption. However, it makes possible to carry out energy balances at the DT level, by comparing records of the meter installed in this equipment with those of the consumers connected to it, if this information is available. This ensures immediate detection of any non-technical loss in the circuit supplied by the DT, allowing timely adoption of the required corrective action. A less expensive option is based on implementing AMI to all consumers connected to a same medium voltage feeder and to the feeder itself, at its end in the high to medium voltage substation. In this case the installation of AMI to the DTs connected to the feeder is avoided and energy balances are carried out at the feeder level. Non-technical losses at that level are easily detected, but it becomes necessary to develop complementary field operations to identify the DTs and related circuits where those losses are being incurred. An intermediate option between installing AMI at the feeder level and for each DT consists of grouping several DTs in energy cells and carrying out energy balances for each of them.

#### (b) Functionality required to the AMI system

Regardless of the criterion adopted to define it, the expansion of the remote metering program to reach large low voltage consumers implies that the total number of points increases to values in the range from 20,000 to 150,000 or more. Capacities and performance requirements of the hardware and software infrastructure needed to properly acquire, transmit and manage the amount of data related to this new dimension of the metering system are completely different from those used if the scope is a few thousand of high and medium voltage customers. These enhanced components characterize the AMI approach.

The primary objective of the use of an AMI system for large low voltage users is to periodically record and monitor their consumption, in order to timely detect and correct any abnormal condition. For that application, the amount of information to be collected from the meter and transmitted to the company's server is limited. However, as the total number of points to be remotely metered and monitored moves to 20,000 or more, the use of individual modem connecting each point with the server becomes an expensive and hard to manage option. It is necessary to use more advanced communication systems, in general based on PLC or RF technologies. Besides, the effective implementation of a state of art MDM software making possible to process such amount of data, detect any potentially abnormal condition and timely adopt the appropriate corrective action becomes absolutely crucial.

(c) Comparative analysis of the criterion for expansion and related requirements

Both approaches for expansion of remote metering to low voltage consumers described in sub-section (a) are fully valid ways of reaching the same destination point: non-technical losses reduced to acceptable values on a sustainable basis. The decision on which is the most convenient way in each specific case depends on several factors, such as total losses in the starting condition, market composition, average tariff level, etc.

The expansion based on individual consumption is supported by evidence provided by some very relevant cases. Two of them are Ampla in Brazil and North Delhi Power Limited (NDPL) in India (some details are provided in Section 6 of this document). Both companies managed to achieve a significant and sustainable reduction in non-technical losses by implementing AMI to each and all customers with recorded power or energy demand below certain thresholds. CEMIG is currently implementing its AMI program applying this criterion.

The author had the opportunity to meet recently (May 2009 and February 2010) with managers in charge of the design and implementation of AMI programs in both companies. Each meeting took place at the company's headquarters where AMI operations are developed. Both management teams provided the same emphatic answer to a specific question: non-technical losses in supply to individual consumers with AMI are fully eliminated. And this is what actually matters.

Figures of the NDPL case are particularly impressive. The company managed to reduce total losses from 53 percent of purchased amounts of energy at takeover by its private owner in July 2002 to 18.5 percent at the end of 2008 and 15 percent in April 2009. According to information published on the company's website ([www.ndplonline.com](http://www.ndplonline.com)) and data obtained in the meeting with Commercial Direction in May 2009, the utility adopted a set of measures to reach this result. One of them was the implementation of AMI to all customers with demand of 15 kW and above, who represent 27.000 users, or 2.7 percent of total, but contribute to almost 60 percent of the revenue. NDPL managers believe that this action explains almost all the impressive loss reduction that the company was able to achieve, and, more importantly, sustain on time.

Communication infrastructure requirements and related investment and operating costs for implementation of AMI to individual large low voltage customers depend on their geographic location. It is clear that costs tend to increase if consumers are sparsely located in the served area, as this obliges to implement more communication links. In an extreme case, individual modems and cellular network links could be installed for each customer, as it is done in the case of high and medium voltage consumers. Although this option could be considered "sub-optimal" from a strictly technical viewpoint (and in fact it is disregarded by several technocrats), this is not the relevant analysis. What actually matters is to compare the total costs and timing of implementation of the AMI system with the results obtained in terms of sustained reduction of losses and protection of revenues. The case of NDPL is paradigmatic:

energy purchases of the company in FY 2008 exceeded 6,000 GWh (million kWh) and average sales price was around US\$ 0.10/kWh. Thus, the annual loss of revenue related to 10 percentage points (600 GWh) of non-technical losses exceeds US\$ 60 million. And the company was able to permanently reduce more than 35 percentage points with a (possibly) sub-optimal one-time investment of less than US\$ 10 million. As it happens with private companies operating in an effectively enforced multi-year incentive based regulatory scheme, NDPL management team immediately perceived the opportunities and threats provided by the regulatory allowance on total losses set for the 4 year period following takeover. If actual total losses exceed the allowance the gap in energy purchases must be paid by the company's shareholders, while if they are below the regulatory target the gap becomes a source of additional revenues that the utility keeps until the following tariff review. Thus, NDPL team took advantage of the enormous opportunity that AMI provided to stop bleeding and start earning money. And it implemented in a very short period a system that made possible to reach that target, avoiding the risk of endless technical discussions on optimal solutions developed while the company is losing huge amounts of money. Unfortunately the situation is in general the opposite in poorly performing state-owned enterprises currently facing high non-technical losses. The author had the chance to meet with IT managers in some of those companies who strongly criticize the sub-optimal technical solution adopted by NDPL and do nothing while their companies continue to show losses above 30 percent.

Although the NDPL case shows that even sub-optimal solutions for communication infrastructure are valid, in general large low voltage customers are concentrated in medium and high income areas. This makes possible to design and implement optimized communication schemes, based on PLC or RF technologies. The most adequate option depends on the location of the targeted customers, geographic constraints and other aspects described in Section 4. A fully case-specific analysis needs to be carried out by a competent expert, in a very short period. Time is critical. The worst approach is to consider implementation of AMI as a long term project.

The implementation of an AMI program based on geographic zones with greater consumption per customer makes possible to take maximum advantage of market concentration in the design and implementation of the AMI communication infrastructure. Both PLC and RF technologies are in principle applicable, depending on local characteristics. The functionality of carrying out energy balances is extremely effective, if properly implemented. However, it requires a basic condition that it is hard to find in poorly performing companies: information on customers connected to each DT or circuit must be reliable and kept permanently updated. Otherwise, developing energy balances will be just a waste of time. This gives PLC systems operating in low and medium voltage a comparative advantage over other technologies. As PLC uses the own distribution network for communications, the link between customer and network transformers is permanently kept, even if the DT used to supply a customer is changed.

In any case, if current information on links between customers and DTs is not reliable, this should not be used as an argument to delay the implementation of an AMI system. As field surveys that must be carried out to improve that information are time and resource consuming, the right decision is implement AMI

first and use energy balances to force and drive the effective execution of those surveys. As already stated, the key objective to achieve is a sustained reduction of non-technical losses. And experience shows that by applying AMI to an individual customer, losses incurred to supply him are eliminated.

Costs of the geographic zones approach depend on the topology of the distribution network. The key aspect impacting on costs is the capacity of the DTs. In networks with large capacity transformers the number of AMI points to be installed at the DTs level is minimized, while networks built with small capacity (in general single phase) DTs will require a great amount of AMI points. However, networks based on small transformers make possible to set a quite accurate link between each DT and the low number of users connected to it. Theft through direct connection to the DT or to the attached low voltage grid can be easily detected, either by the company or by the own honest customers, who are directly affected by the clandestine users. This effect can be reinforced by installing a low voltage breaker inside each DT, calibrated to trip if the allowed demand is exceeded, with a certain tolerance.

#### (d) Costs

Current market prices of AMI systems for low voltage customers are in the range of US\$ 80 to US\$ 130 per connected point, including communications hardware and MDM software. A device allowing remote disconnection and reconnection can be added at US\$ 50 to US\$ 70. These are direct implementation costs of the AMI system. Sometimes the customer is already metered using electromechanical equipment. Thus, the installation cost of the new meter must be added (typically US\$ 50 to US\$ 60).

If AMI is also installed in DTs to enable energy balances, total investment costs per customer may reach US\$ 250 to US\$ 350, depending on the topology of the distribution network. The upper bound of this interval corresponds to 3,500 kWh consumed at a tariff rate of US\$ 0.10 per kWh. This is less than the amount consumed in 6 months by a customer with 600 kWh/month average consumption. A one-time investment equivalent to that monthly billing ensures that the customer will be billed according to his real consumption during the whole economic life of the AMI system (around 15 years).

#### 5.1.3.3 AMI as a component of the distribution system for non-manageable (high risk) areas

AMI is a key component of the approach called medium-voltage distribution (MVD), which is adopted for construction and operation of electricity networks used to supply consumers located in areas where access to the service company is constrained due to safety or other reasons. MVD was initially designed and implemented by the Brazilian company Ampla, providing electricity service to 2.3 million customers in the Brazilian state of Rio de Janeiro. The market supplied by Ampla is mainly residential, and its geographic density is low. Around 1.6 million of the company's customers live in areas where the company can carry out regular field operations. In those zones Ampla was able to reduce non-technical losses in a short period after takeover by its private owner in 1996. However, sustainability of those improvements was not ensured, as willingness to steal electricity in the State of Rio de Janeiro is high at all social levels. The remaining 670,000 Ampla's customers are located in slums where crime associated

with drug traffic makes regular operations almost impossible. In 2003 the company started to develop a new approach to serve those areas, based on a specific network design to prevent theft, combined with the application of AMI. The company named it “Rede Ampla (RA)”. Other similar approaches for network design are usually referred as “medium voltage distribution (MVD)”.

In MVD networks, each individual consumer connection starts directly from the low voltage terminal of a small capacity single-phase DT, and is laid above the medium-voltage line. Thus, the low-voltage grid is eliminated. Besides, meters are not installed at customers’ premises, but in an armored box on the same pole used for the DT, and AMI is used to read their consumption records. The RA is a combination of the MVD and AMI. Between 2003 and 2009 Ampla implemented it for the supply to more than 300,000 consumers living in dangerous slums. RA is an expensive solution requiring significant investments both in new distribution networks and AMI. Investment ranges from US\$ 400 to US\$ 600 per customer, depending on density and other factors. But it is the cheapest *sustainable* solution in these areas. Experience shows that a solution requiring the company to perform activities at the site does not work, as access to the area is constrained. Knowing that there is fraud and theft in an area does little if no corrective actions can be taken. Ampla estimates it needs to supply another 370,000 consumers using that distribution scheme to achieve an acceptable value of non-technical losses. In a meeting with the managers responsible for RA in February 2010, they informed that non-technical losses are eliminated through the application of the system and theft moves to non-protected networks. They are aware that the solution is to reach the whole theft-prone area with the RA. The projects needed for that purpose have been planned and are under execution. More importantly, the Brazilian electricity regulator recognizes that RA is the cheapest option making possible to reach acceptable non-technical losses in those dangerous areas. Although investment costs are considerably higher than those of conventional networks, their feasibility arises from comparison with a higher allowance on non-technical losses (energy purchases). It is less expensive for honest consumers to pay for the investment and operating costs of RA than for additional energy purchases to cover high non-technical losses. The RA scheme and the way Ampla evolved towards its full implementation are described in Section 6 of this report. Distribution schemes following the same principles of the Ampla case were implemented by several distribution companies in other developing countries in Latin America and South Asia.

## **5.2 Prepaid consumption in low-income areas**

Application of AMI, together with a commercial management information system (CMS), makes implementation of pre-paid consumption of electricity for low-income consumers, which is generally a very good commercial option for them and for the utility. Voluntary pre-paid consumption proved to be a viable option to make possible access and sustainable supply to low-income users. It also makes a more transparent use of direct subsidies possible, when necessary.

AMI enables replication in the power sector of the tremendous success of pre-paid consumption in the mobile phone industry—key to expanding use of mobile phones in developing countries. There are dozens of cases of very poor countries in Africa, Asia, and Latin America with a booming mobile phone industry, often by-passing land lines. According to the International Telecommunication Union, by end-2007, about 60 percent of mobile subscriptions in the whole world were prepaid.<sup>8</sup> The percentage of prepaid mobile subscriptions is well above 60 percent in poor countries; although prepaid tariffs tend to be more expensive (per minute) than postpaid tariffs, they are often the only practical payment option available to low-income users who might not have regular income. Implementation of AMI, together with a commercial management system (CMS), makes pre-paid consumption of electricity possible. Credit bought by consumer is loaded in his account in the CMS; many options are available for purchase and loading, including use of mobile phones. The company can easily implement operational procedures allowing the customer to have access to the remaining credit, receive alert messages from the company when the credit is about to expire, buy new credit, receive disconnection message, etc. The company can apply remote disconnection and reconnection included in the AMI devices used for low-voltage consumers in cases of credit expiration and non-renewal in the same way pre-paid mobile phones work.

The AMI approach for pre-paid consumption has several significant advantages compared to the classic pre-paid card meters widely used in South Africa and other countries. Two very important ones are: (i) significantly lower hardware costs; and (ii) permanent monitoring consumption allowed by AMI, which is not possible with the classic card meter. With a card meter, the company has no information on real time consumption while the user has credit and the cardholder can by-pass the meter without being detected, unless field inspections are performed.

Conventional prepayment meters protect only sales and revenues related to the prepaid amounts. They proved to be a successful tool to promote consumers' discipline to pay for electricity in cases where theft was not a major problem. They are also a very good option for supply to new users in rural areas (the case of Morocco is an impressive example). However, they are not aimed at protecting revenues related to the amounts of energy actually consumed by the user under the prepayment regime. Their contribution to loss reduction is actually limited and, in practice, they don't solve the main problem in areas where theft and willingness to incur in irregular consumption are high.

AMI pre-paid consumption has all the advantages and features of the classic option and adds to them the effectiveness of the remote metering tool to achieve a sustained reduction of non-technical losses.

Application of AMI enabled prepayment schemes has been limited. They started to be implemented in 2008 by Ampla but could not achieve significant progress due to a legal constraint: utilities must inform their customers 15 days in advance of the date of a service disconnection related to commercial debts.

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<sup>8</sup> Measuring the Information Society – The ICT Development Index 2009 – International Telecommunication Union, available at [www.itu.int/publ/D-IND-ICTOI-2009/en](http://www.itu.int/publ/D-IND-ICTOI-2009/en).

This is completely contradictory with the concept of prepaid consumption. The elimination of that barrier is currently being discussed by Brazilian lawmakers.

In general, application of prepaid consumption schemes should be considered once the overall problem of high non-technical losses is solved, as this is the key aspect jeopardizing the financial viability of the distribution company. The case of electric service in Mozambique is a good example. The state owned vertically integrated utility Electricidade de Moçambique (EDM) serves around 700,000 customers in the country. In spite of having 73 percent of its customers under the prepayment scheme (mandatory regime for most of them), current total losses in supply are around 30 percent of generated energy, and increasing from year to year.

While the company continues to incorporate large amounts of new electricity users under the prepayment regime every year (access rate in the country moved from 7 percent to 14 percent in 3 years), it currently serves 3,650 (0.5 percent of total number) large consumers representing 47 percent of total sales. And those customers are managed using conventional approaches for metering, reading and monitoring their consumption. What EDM should do to reduce losses and protect its main source of revenues on a sustainable manner seems quite evident. But the company is just implementing a pilot AMI project, while continues to face severe financial shortages.

### **5.3 Implementation of demand side management actions to maximize efficiency in electricity consumption for medium and large customers in all categories**

AMI applied to medium and large customers in all consumers' categories can allow the optimization of electricity use, by offering users relevant real-time information on price changes, duration of peak periods, cumulated consumption, alerts, etc. Recent experience, both in developed and middle income developing countries, illustrates that medium and large residential consumers may be responsive to clear and timely information on pricing options **if they perceive potential benefits for them**, in the same way as large industrial and commercial consumers. Those pricing options range from the classic "static" two-charge (demand and energy) time-of-use tariffs to the more sophisticated dynamic pricing options.

AMI driven demand side management (DSM) applications appear as a natural second step in utilities in developing countries facing significant theft and fraud, once this situation is eliminated with the help of that tool. It focuses on energy efficiency from the country-level standpoint. It is well known that a pricing system providing users with the right signals on actual costs of supply is an absolutely critical condition to promote efficiency in consumption. And by setting up a direct link between the consumer and the utility, AMI makes possible to promote energy efficiency in two ways. First, with the proper pricing signals from utility companies passed on to large and medium sized consumers, these consumers are given the opportunity to react to incentives, for instance by decreasing consumption during peak loads

when generation tends to be most expensive. In several cases, this implies that the country could then potentially decrease the use of fossil fuels for electricity generation. Secondly, by collecting the most up to date load curve information via AMI, utilities can effectively optimize energy purchases and development of their networks, which leads to optimized pricing systems in the long term as well. This can bring significant benefits. In its *Energy Outlook 2008*, the International Energy Agency estimates that half of the quantitative targets that need to be achieved to limit global temperature increase to 2 degrees in 2030 can be obtained through energy efficiency actions on the demand side.

Although there is general agreement on the above-described concepts, the effective implementation of AMI enabled dynamic pricing DSM has been until now limited to a set of pilot tests, mainly in the United States. A recent report prepared by two experts of the Brattle Group provides an interesting summary of some of those tests and their results<sup>9</sup>.

The report starts by recognizing that since the energy crisis of 2000-2001 in the western United States, much attention has been given to boosting demand response in electricity markets. One of the best ways to let that happen is to pass through wholesale energy costs to retail customers. This can be accomplished by letting retail prices vary dynamically, either entirely or partly. For the overwhelming majority of customers, that requires a changeout of the metering infrastructure, which may cost as much as \$40 billion for the US as a whole. While a good portion of this investment can be covered by savings in distribution system costs, about 40 percent may remain uncovered. This investment gap could be covered by reductions in power generation costs that could be brought about through demand response. Thus, state regulators in many states are investigating whether customers will respond to the higher prices by lowering demand and if so, by how much.

Aiming at providing a contribution to the assessment on demand response, the study surveys the evidence from the 15 most recent pilots, experiments and full-scale implementations of dynamic pricing of electricity. The authors find that demand responses vary from modest to substantial due to a variety of factors, some of which can be controlled such as electricity prices and whether or not enabling technologies are present, and some of which cannot be controlled, such as the design of the experiment and its location.

The authors find conclusive evidence that households (residential customers) respond to higher prices by lowering usage. The magnitude of price response depends on several factors, such as the magnitude of the price increase, the presence of central air conditioning and the availability of enabling technologies such as two-way programmable communicating thermostats and always-on gateway systems that allow multiple end-uses to be controlled remotely. They also vary with the design of the studies, the tools used to analyze the data and the geography of the assessment. Across the range of experiments studied, time-

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<sup>9</sup> Household Response to Dynamic Pricing of Electricity – A Survey of the Empirical Evidence – Ahmad Faruqui and Sanem Sergici; The Brattle Group, February 2010.

of-use rates induce a drop in peak demand that ranges between three to six percent and critical-peak pricing tariffs induce a drop in peak demand that ranges between 13 to 20 percent. When accompanied with enabling technologies, the latter set of tariffs lead to a drop in peak demand in the 27 to 44 percent range.

The report emphasizes the need for further work on the empirical data. However, its authors state with confidence that residential dynamic pricing designs can be very effective in reducing peak demand and lowering energy costs. They believe that demand response programs that blend together customer education initiatives, enabling technology investments, and carefully designed time-varying rates can achieve demand impacts that can alleviate the pressure on the power system. They recognize that dynamic pricing regimes also incorporate some uncertainties such as the responsiveness of customers, cost of implementation and revenue impacts. However, they think these uncertainties can be addressed to a large extent by implementing pilot programs that can help guide the full-scale deployment of dynamic pricing rates.

Although the conclusions of the report are strongly supported and seem completely consistent, we believe that, as it usually happens with studies and assessments on demand side management applications conducted by monopolistic utilities, they underestimate the importance of the actually critical issue to be addressed: **responsiveness of customers**. Availability of technologies providing the required functionality and features is a necessary condition for the successful implementation of DSM programs. But it is far from being sufficient. If the DSM program is not perceived by customers as something that represents a real benefit for them, without implying unacceptable changes or sacrifices in their normal lives, it will clearly fail.

The need of management oriented by customer satisfaction is absolutely obvious for companies providing goods or services in actually competitive markets. However, some real cases show that not always utilities operating under monopolistic conditions run their business following this key concept. Not surprisingly, in March 2010, Commissioner Nancy Ryan of the California Public Utilities Commission told the “Metering America” conference that “it’s imperative that the installation of smart grids and smart meters be seen as something done for customers and not something done to customers<sup>10</sup>”. Utility rates based on time-of-day pricing related to the cost of producing electricity must be coupled with extensive customer communications and education campaigns, or the effort to align consumers and true market costs will be wasted”. In the same line, a recent study on the smart energy market sponsored by many energy and technology companies in the US and conducted by Kema examined residential customer awareness, acceptance and value of smart grid enabled electricity offers, home energy technologies and

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<sup>10</sup> [www.metering.com](http://www.metering.com), published on March 18, 2010.

rate plans (“smart energy”). The study found that success of demand energy depends on customer acceptance<sup>11</sup>.

The above-cited references are just the first that highlight the importance of customer response and follow the publication an impressive set of documents, speeches and other communications focused on the enormous potential of the smart grids concept and how currently available technology (in particular AMI) provides the features and functionality needed to implement DSM programs. Comments by Ms. Ryan and contents of the Kema report also follow the big failure of some utilities that implemented DSM programs (in essence time-of-use tariffs) immediately after incorporating AMI systems, without a previous evaluation of their impact on their customers. As those programs implied increases in electricity bills for many customers, they created an understandable negative reaction on them. Accuracy of the AMI technology was severely questioned, obliging the regulators to order check remote meters against electromechanical devices used before the companies decided to implement the new tariff regime<sup>12</sup>. Although this may seem ridiculous from a strictly technical perspective, it was absolutely necessary to show consumers they were not being cheated and try to restore the confidence in the service provider. However, it seems quite clear that those DSM programs will not continue, simply because they are inconvenient for customers. And it will be very hard to replace them by well designed initiatives that, under certain conditions, may represent real benefits for consumers. Management of utilities driven by the “monopolistic culture”, that is, ignoring customers’ needs and preferences, can have potentially devastating consequences.

Application of dynamic pricing in developing countries has been limited to the use of time-of-use (TOU) tariff schemes for medium and large customers in some or all categories, including sometimes both power demand and energy charges (binomial rates). Residential consumers are in general free to choose between those TOU schemes and the conventional system based on a uniform energy rate. In practice, most residential consumers are metered using electromechanical devices that only record energy (uniform tariff). Utilities showing acceptable levels of total losses avoid changing the meters before they reach the end of their economic lives. This is particularly evident if the tariff regime is based on recognition of replacement costs, which is the predominant situation in Latin America. In this case, the utility has strong incentives to avoid the replacement of equipment that could continue to be used without deteriorating service quality. As an example, in Brazil only 7.39 percent of the total number of electricity consumption meters is electronic. More than 80 percent of the meters countrywide have 10 years or less. The electricity regulator ANEEL has launched a public consultation process to discuss the incorporation of electronic metering (not necessarily remote) for low voltage users. And nobody could argue that the performance of the power sector is bad. The exceptional situations are those of companies with high losses. And, as described in the analysis of the Ampla case, ANEEL recognizes investments in remote metering as the least cost option to reduce losses on a sustainable manner.

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<sup>11</sup> [www.metering.com](http://www.metering.com), published on March 08, 2010.

<sup>12</sup> [www.metering.com](http://www.metering.com), “Oncor develops smart meter verification plan”, published on March 08, 2010.

Recent experiences (Brazil rationing in 2001, Chile big increases in electricity tariffs in 2008) show that medium and large residential consumers are more responsive to significant changes in overall average tariff level (monthly bill) than to TOU options. Those consumers will significantly reduce their consumption in a short time if exposed to big increases in the average tariff level. But they are likely to adopt complex TOU regimes only if this implies a significant economic benefit for them (in terms of the amount they pay for electricity supply) without obliging them to implement changes adversely affecting their quality of life. Thus, the effective viability of DSM actions based on TOU schemes depend on the calculation of the rates in each block, which should be carried out in a way that ensures they reflect total costs of efficient service provision in each of them. Costs should be computed considering long-term expansion of generation, transmission and distribution facilities needed to provide service meeting quality standards set in the applicable regulations. This requires the development of planning studies aimed at identifying options available for the country to expand its power sector and building-up scenarios to be evaluated, taking into consideration aspects such as security of supply, environmental constraints, the impacts of climate change, etc. Total costs of efficient supply arising from the technical and economic evaluation of each scenario, and their variation in time of day, will determine the effective viability of DSM programs. Although the evaluation is fully case-specific, some general comments can be made. On one side, generation costs, which already represent a major share (70 percent or more) of total rates paid by end consumers in most countries, are likely to increase their impact on the average tariff level in the medium and long term. This is a consequence of future global scenarios characterized by high prices of energy primary resources and conversion equipment. In this context, the relative impact of network costs on average tariffs will decrease on time. Thus, if generation costs do not change significantly in time of day (which is the case in systems with large installed capacity in hydropower plants or low operating cost base load thermal stations), TOU schemes based on real costs of supply are unlikely to be attractive. On the contrary, TOU regimes could be convenient for customers if their rates reflect large differences in generation costs in the same day arising from the use of peak plants running on expensive fuels.

In Uruguay there is a non-mandatory TOU tariff for residential consumers, with a US\$ 250/MWh rate in peak period (5 pm to 11pm), and a US\$ 90/MWh in the remaining 18 hours each day. Conventional residential tariff has a single US\$ 170/MWh rate. In 2006 the author decided to change to the TOU option in his home after installing timers in all the water heaters to disconnect them during the peak period, and replacing all lamps by CFLs. Besides, the use of electric air-conditioning equipment (for cooling and heating, we use reversible split units) is minimized during the peak period. This represented a tolerable loss of comfort (weather is quite mild in the capital of the country), compensated by 15 percent monthly savings in electricity bills compared to the single rate tariff. But it could be tested that if consumption in the peak period slightly moved upward, amount of the electricity bill was significantly higher than with the conventional single-rate option.

In summary, it can be stated that the effective application of AMI in dynamic pricing, time of use tariffs and other options for DSM and demand response programs crucially depends on the viability of designing and implementing programs that are perceived by customers as convenient for them. And this implies to

get significant reductions in electricity bills with limited negative impact on comfort. If well designed pricing systems are applied, the viability of the DSM programs will be determined by the amount of differences between total costs of efficient supply in day periods and the ability of customers to manage their consumption pattern to take proper advantage of those differences. The technological feasibility is well known, but it is far from being the critical element.

## **6. Relevant examples of application of AMI**

### **6.1. Ampla (Brazil, Rio de Janeiro State)**

Ampla serves 2.5 million customers (7 million people) located in 66 municipalities in a 32.188 km<sup>2</sup> area, which corresponds to 73percent of the state of Rio de Janeiro. Annual sales are 9.364 GWh and total staff 8,652 employees.

It is a low density and complex market, composed mostly by residential consumers. Although Rio de Janeiro is the second most industrialized state in Brazil, most of these industries are located outside Ampla's concession area. Energy theft and bad credit are significant in some served zones. They are not directly related to poverty of served population, but to factors such as inhabitants living in slums, urbanization and violence (high rate of homicides per 100,000 inhabitants).

In 2003, overall losses in the concession area served by Ampla were high (around 25 percent of injected energy). Through energy balances at the medium voltage feeders level the company could determine that losses were concentrated in specific regions. Around 30 percent of Ampla's 2.1 million customers are located in the São Gonçalo, Itaboraí, Magé, Duque de Caxias and Niterói municipalities, and most of them are residential consumers. But 50 percent of the company's total losses come from those zones. Application of traditional techniques failed to reach sustainable results in those areas, as 30-40 percent of consumers formerly regularized through conventional field inspections made fraud again in the following year

Taking into consideration the distribution of losses throughout concession area, as well as the composition of the served market, in 2003 the company launched three initiatives aimed at achieving a sustainable elimination of non-technical losses (theft and other ways of unmetered consumption): (i) the "Rede Ampla", implemented in supply to small low voltage consumers (mostly residential) living in geographic areas showing high overall losses; (ii) the "Anti-Theft Machine", applied to large consumers supplied in medium voltage, with indirect metering; and (iii) the "Sentinela" system, used for large and medium low voltage consumers.

#### Rede Ampla

Initial phase of “Rede Ampla” was implemented in mid-2003 and identified as “Rede DAT” (aerial transverse distribution). It consisted of a fully new design of the medium and low voltage distribution networks, aimed at making almost impossible direct connection to them of irregular consumers. Main characteristics of the DAT design are shown in Figure 6.1. Results obtained from its implementation were very positive from the beginning, in terms of eliminating direct connections to the distribution grid. However, quite soon Ampla noticed that DAT was insufficient to eliminate theft, which moved to the component of the supply circuit that remained accessible to users: the consumption meter. Thus, it became necessary to complement DAT with physical isolation of meters from users and incorporation of automated meter reading (AMI) to read and monitor consumption, together with remote disconnection and reconnection of electricity supply.

This “AMI-upgraded” version of the “Rede DAT” is the “Rede Ampla”, implemented in February 2004. The company developed technical specifications for all the components of both systems, which are protected by patents.

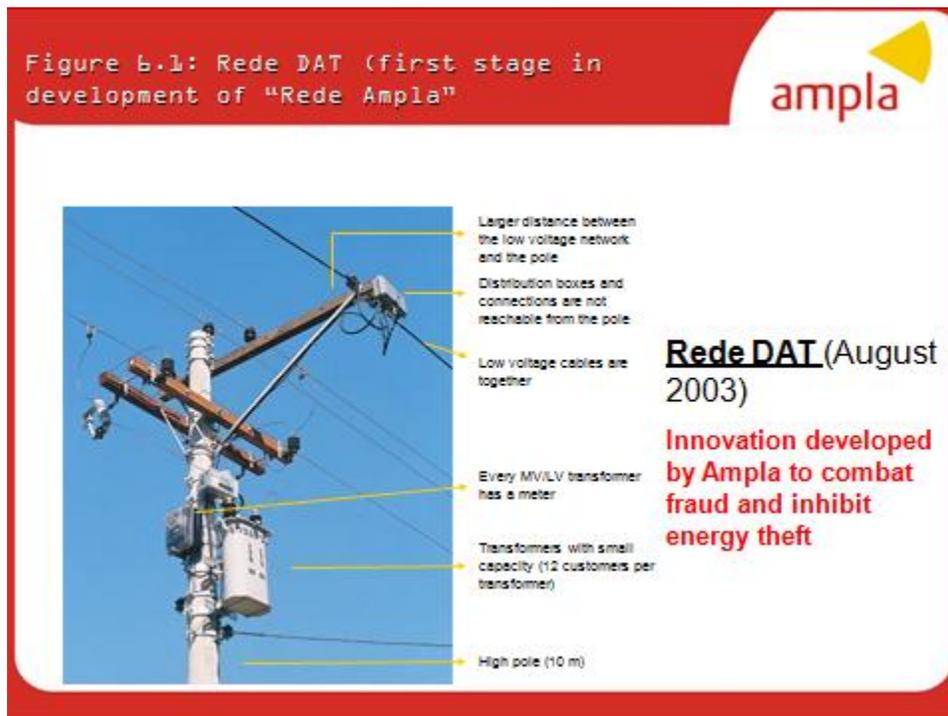
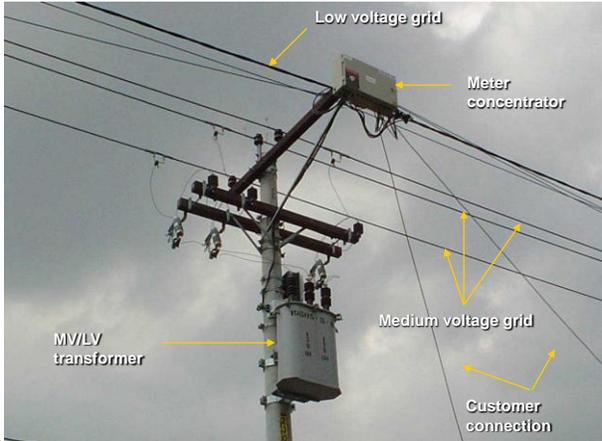


Figure 6-2: Rede Ampla: Rede DAT + AMI

ampla

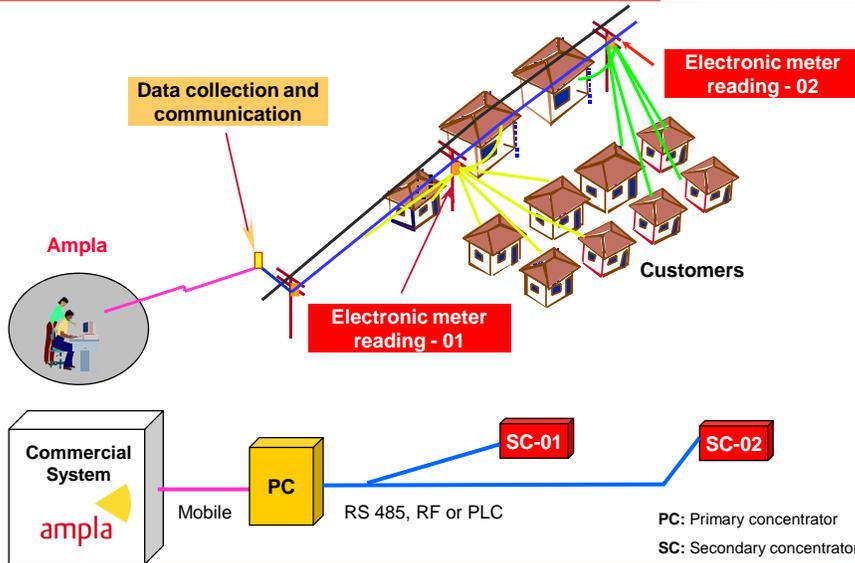


**Rede Ampla:**  
(February 2004)

An upgraded version of Rede DAT, incorporating an Automated Meter Reading system (AMR)

Figure 6-3: Rede Ampla functional scheme

ampla



Results of the application of the “Rede Ampla” system are impressive. In a meeting with World Bank officials in the company’s headquarters in São Gonçalo in February 2010, managers in charge of the program stated emphatically that non-technical losses in supply to consumers using the “Rede Ampla” are

fully and permanently eliminated (“zero”). They added that the company has still to implement this approach to other 370,000 consumers to reach an acceptable and sustainable steady state condition in terms of non-technical losses. In July 2005 and September 2006 the Brazilian development bank (BNDES) approved loans to Ampla totaling US\$ 212 million for the massive implementation of the “Rede Ampla” in geographic zones with high losses. As per December 2007, Rede DAT was implemented to 560,000 customers, and 380,000 of them had remote metering (Rede Ampla).

Concerning organizational aspects for operation of “Rede Ampla”, the company developed two providers of the AMI system and fully outsourced to them all the field operations related to installation, operation and maintenance of its components. Ampla’s team in charge of AMI receives the data provided by the metering system, process them using the MDM software and define eventual corrective actions that may be required.

A very important issue related to the implementation of the “Rede Ampla” system is the regulatory approach followed to ensure access by the electricity users to records of the consumption meter. Application of AMI was authorized by the Brazilian electricity regulator ANEEL only in June 2005. Until then, the meter had to be installed in the customer’s premises. The concept was that the user had the right to have access to the meter itself. In June 2005 ANEEL adopted a resolution that implied a paradigmatic change: the customer’s right is to have access to the meter reading at any time, at his convenience. To comply with this resolution, Ampla implemented a set of options to its customers, including, among others: information in the bill, personalized attention in commercial agencies, 24 hours x 7 days call center with toll-free numbers, dedicated websites (including the chat option), submission of SMS to mobile phones on request, etc. The company allocated very high priority to this critical aspect. This helped to reduce social unrest created by the implementation of the “Rede Ampla” in certain areas, shown by demonstrations and other ways of protest, which fully reconfirmed the effectiveness of the solution to eliminate non-technical losses.

In addition to those related to reduction of non-technical losses, the implementation of the “Rede Ampla” had other significant benefits. They include, among others, lower operation and maintenance costs, higher accuracy in consumption metering, improvement of service quality (frequency and duration of interruptions in electricity supply decreased around 50 percent from pre-implementation values), better urban planning and reduced visual pollution. Rede Ampla makes also possible to apply pre-paid consumption regime, by combining the remote disconnection and reconnection facilities with the commercial management system (CMS) operated by the company. However, the effective use of this tool has been limited by the existence of laws regulating notifications related to service disconnection, whose derogation is currently being analyzed by the Brazilian lawmakers.

### AMI system for individual large consumers

Ampla implemented remote metering of all its high and medium voltage customers and largest low voltage consumers to eliminate non-technical losses and protect revenues from sales to that segment on sustainable basis.

For high and medium voltage consumers the company decided to install a complete AMI system in an armored box located outside the customers' premises. That system, referred as the "anti-theft" machine, includes metering transformers, meter, communication equipment and mobility sensors to detect attempts to manipulate the box. Total investment cost is around US\$ 5,000 per point of supply. Payback period is less than one year, based on recovery of revenues due to previously unmetered consumption. Ampla team ensures that recovery is permanent (non-technical losses in supply to customers with anti-theft machines are zero).

A similar approach was followed for largest low voltage consumers, and is referred as the "Sentinela" machine. Total investment in this case is around US\$ 4,000 per point of supply and sustainable recovery of previously unmetered consumption ensures an internal rate of return of the AMI project above 75%.

Figure B-4: Externalization of metering system ("anti-theft machines") for high and medium voltage large consumers

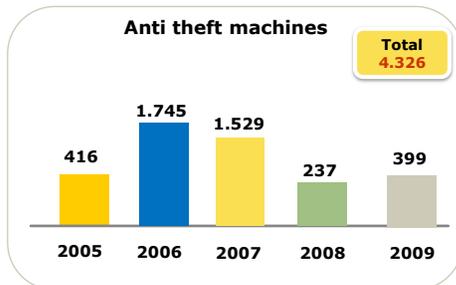
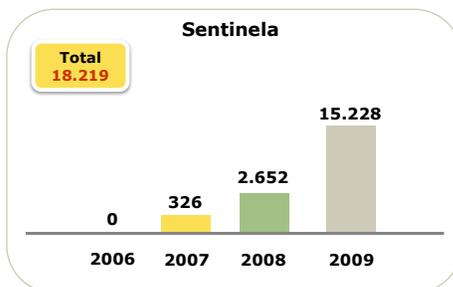
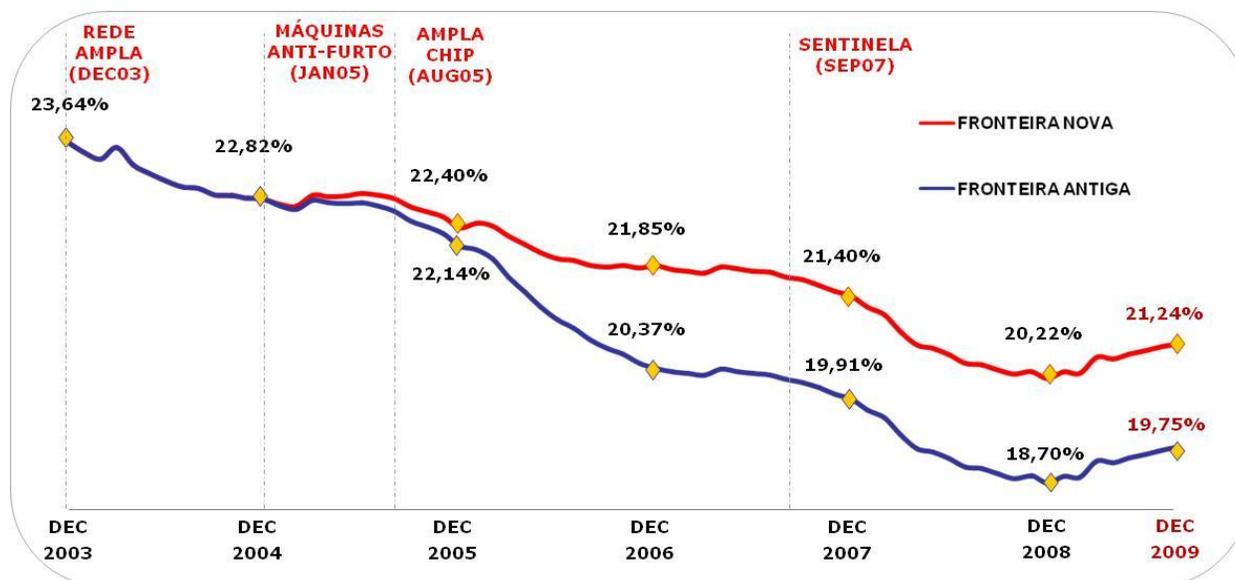


Figure 6.5: SENTINELA - AMI solution to reduce non-technical losses in supply to low voltage large consumers



- Cost per point of supply: US\$ 4,000
- Internal rate of return: 75 %

From takeover by its private owner in 1997 the company reduced total losses from around 30 percent to 24 percent by applying conventional techniques (field inspections and other actions to promote market discipline) in its 1.6 million customer segment located in regular zones. However, sustainability of that reduction was at risk. Results achieved from 2003 in the implementation of the different stages of its comprehensive AMI program reaching large consumers and users living in dangerous slums are shown in the following Figure 6.5. They show that the fight has been hard in an extremely challenging environment (probably unique in the world), due to the combination of widespread violence in several zones (involving close to 670,000 customers), corruption and social misbehavior (at all income levels). Ampla management is fully confident that, once the AMI program is implemented in its full scope, results in terms of total losses will be comparable to those of other companies of similar characteristics in terms of served market and geographic area. More importantly, it will be possible to sustain them in the extremely severe environment where service is being provided.



**Figure 6.5: Evolution of losses in Ampla from startup of the AMI project**

## 6.2. North Delhi Power Limited (NDPL) India

North Delhi Power Limited (NDPL) was founded on July 1, 2002 through public/private partnership framework as a 51:49 joint venture between Tata Power and Government of Delhi.

NDPL distributes electricity in the north and northwest parts of Delhi and serves a population of about 5 million people spread across 510 square kilometers (km<sup>2</sup>). It has a registered consumer base of about 1 million, a peak load of 1,180 MVA, and an annual energy consumption of about 6,200 GWh.

Six years into its inception, NDPL has achieved impressive results in reducing total losses, moving from 53 percent at takeover in July 2002 to 18.5 percent at the end of 2008 and 15 percent in April 2009. According to information published on the company's website ([www.ndplonline.com](http://www.ndplonline.com)) and data obtained in personal meetings with Commercial Direction, the various measures taken to achieve this loss reduction include the following:

- Implementation of automated meter reading (AMI) for metering, reading, and monitoring consumption of all consumers with demand of 15 kW and above, who represent 2.7 percent of total, but contribute to almost 60 percent of the revenue.
- Installation of medium voltage distribution (MVD) networks in theft-prone areas, with direct connection of each consumer to the low voltage terminal of the supply transformer

- Replacement of old erroneous electromechanical meters with accurate electronic meters
- Energy audits up to the distribution transformers (medium to low voltage) level
- Aggressive enforcement activities with scientific inputs and analysis
- Public participation in controlling theft through the concept of “social audit”
- Collaboration with non-governmental organizations for creating awareness in slums regarding the dangers associated with direct tapping of electricity from live wires.

NDPL’s Commercial Direction considers implementation of AMI for large consumers the reason explaining most of the quantitative results obtained, as the other measures are at less advanced implementation stages.

In addition, the company is taking advantage of the application of a performance-based multi-year tariff regulatory regime. Performance targets (including allowance on total losses) are set by the regulator for a four-year tariff period. If the company meets or surpasses those targets, it is allowed to keep the surplus profits (additional revenues and reduced costs) until the next tariff period. NDPL is operating consistently below the allowed total losses. Thus, the difference between the allowed revenue (based on the performance target) and the actual amount of energy purchased is retained by the company as an additional profit. For the next tariff period, the regulator will set new targets for losses starting from the values actually achieved by NDPL. The performance-based, multi-year tariff regulatory regime has shown to provide the right incentives to the regulated companies to improve their performance.

NDPL conceptualized and implemented an AMI system referred as the BIOS, reaching 26,400 customers: around 1800 in the “Key Consumers Group” (demand above 100 kW) and 24,600 in the “High Revenue Base Consumers Group” (demand >15 kW). Those customers represent 60 percent of the total revenues of the company and the AMI system is assuring a sustainable protection of them. Its application is now being expanded to reach customers with single phase meters.

NDPL developed its own web based application “AMRDA” meter managing system to achieve interoperability among meters manufactured by various providers. This interoperability between meters have been achieved without deviation on part of security and protocols and is in accordance with standards circulated by the Indian authorities on interoperability. That in house development makes possible NDPL to choose its meter supplier and virtually any meter can be integrated into the system.

The company also developed an experienced pool of engineers in house who are dedicated to the analysis of data downloaded from the meters. Artificial intelligence built in into the AMRDA software helps in flagging exceptional cases to the analysis group which then undertakes a comprehensive analysis of these cases in terms of load profile, billing data and tamper events to identify cases of intentional manipulation.

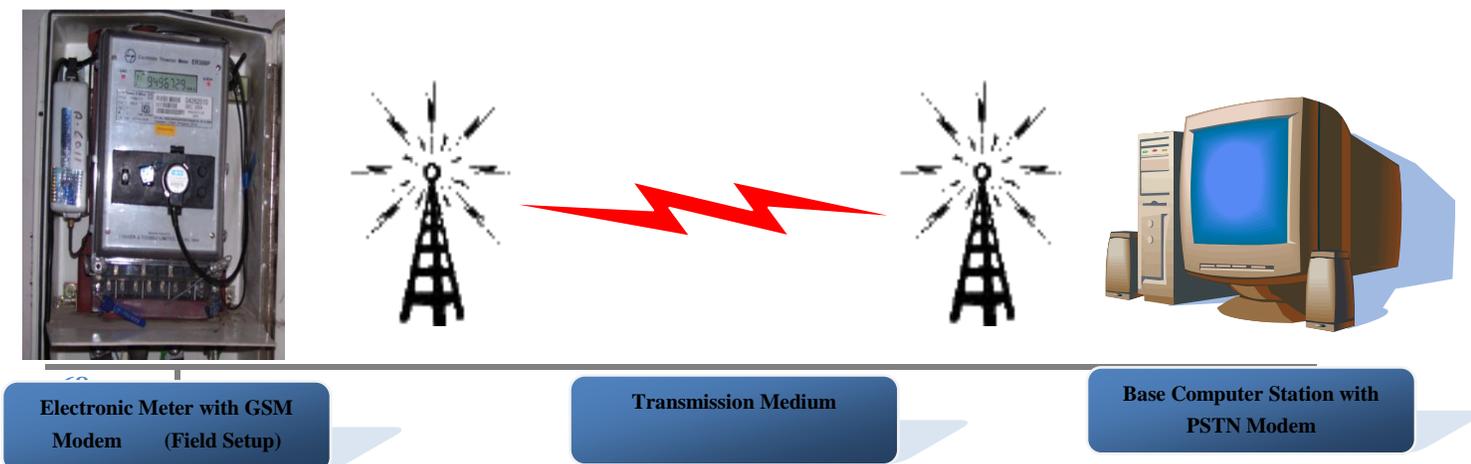
The main benefits realized by NDPL due to the implementation of the AMI system are:

- Enhanced consumer billing: (i) improvement in billing efficiency and reduction in provisional billing; (ii) reduction in consumer complaints on account of considerable reduction of manual interventions
- Enhanced collection: identification of cases where consumers have been involved in “dishonest abstraction of electricity” (Approx. 20000 kW booked after AMI implementation)
- Reduction in the billing cycle time.
- Identification of cases for transfer from lower tariff category to higher tariff category on account of load violations.
- Identification of other cases of unmetered consumption (users with suppressed meter readings on account of connivance with the meter reader).

The most relevant issues and in the NDPL AMI case, which become important sources of emerging lessons, are:

- Even if the communication system (individual direct links between meter modem and company’s server) can be criticized as sub-optimal by some technocrats, it made possible fast implementation of the system, allowing the company to achieve impressive results in terms of sustained reduction of non-technical losses, with enormous financial impacts. NDPL could manage in a short period to move from financial burden faced while actual losses exceeded the regulatory allowance to additional revenues when sign of that difference was reversed.
- The company gave high priority to the development and implementation of state-of-art software (meter data management) to process all the data provided by the AMI system. This is actually crucial to make proper use of the system capabilities and functionality, in particular those allowing timely detection and correction of abnormal situations in consumption metering (theft, tampering, collusion, etc.).

**Figure 6.6: Architecture of AMI system implemented by NDPL**



### 6.3. Enel (Italy)

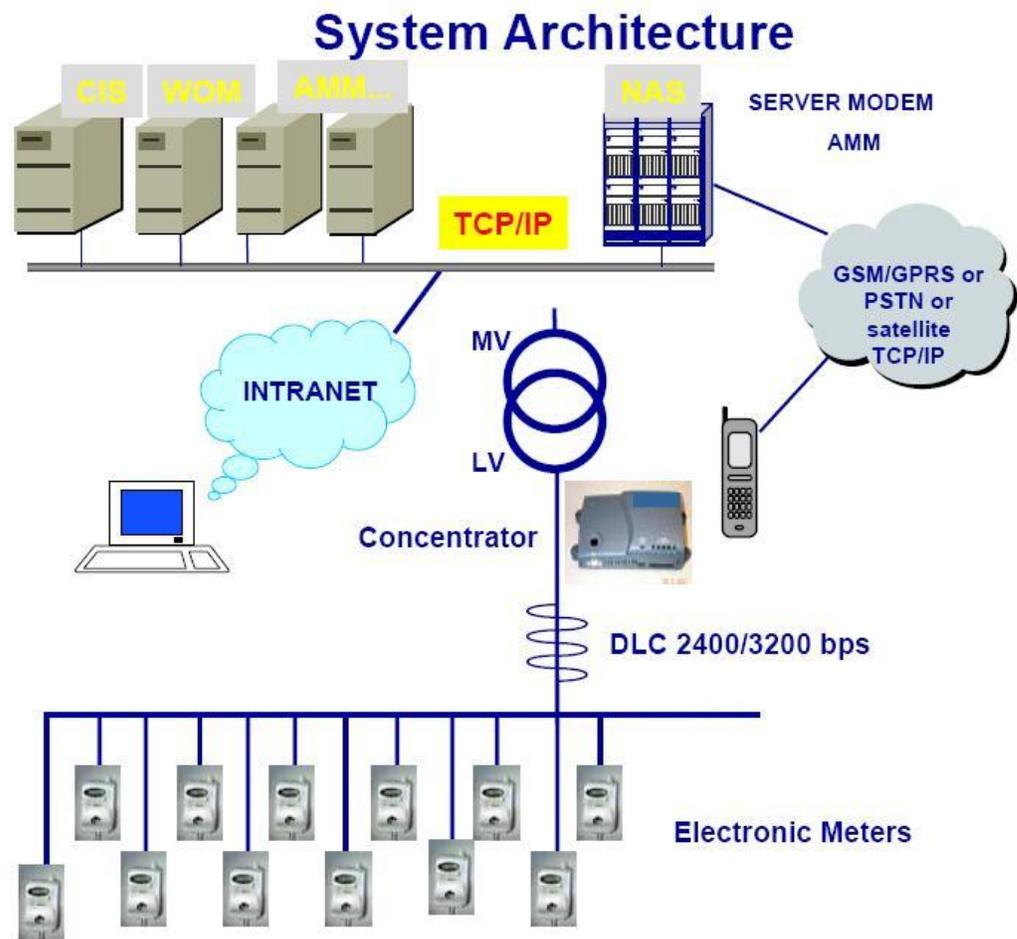
The Italian state-owned electricity company Enel implemented the biggest AMI system currently operating in the world. The system reads and monitors consumption recorded by approximately 33 million meters in the whole country.

Development of the AMI project started in the mid 90s and the system was initially implemented to the company's large consumers (currently around 92,500). After this first successful stage, the company carried out a pilot project involving 70,000 low voltage clients, before deciding on massive application in this segment. The power line communication (PLC) technology was used in that pilot. As results were positive, and, after evaluating some cases in the United States, at the end of 1998 Enel decided to expand the AMI project to reach all its customers. The project was fully implemented in less than five years, at an average rate of 20,000 meters installed each day. The current scope of 33 million meters with AMI technology, combined with bi-monthly meter readings for billing purposes, implies 198 million readings per year.

	2001	2003	2004	2005	2006	2010
Meters Installed	150,000	13,000,000	21,000,000	27,000,000	29,800,000	33,000,000
Remotely Managed	N/A	10,000,000	18,800,000	26,000,000	28,800,000	33,000,000
Bimonthly Read	N/A	1,000,000	4,300,000	25,000,000	28,700,000	33,000,000
TOTAL LECTURAS		6,000,000	25,800,000	150,000,000	172,200,000	198,000,000

Although the reduction of theft and fraud in certain areas in Southern Italy was one of the objectives of the AMI project, its main purpose and source of financial viability is the drastic reduction achieved in meters reading costs. Total investment was 2,100 million Euros and payback period 4.5 years.

The AMI system includes a concentrator installed in each medium to low voltage distribution transformer (currently around 350,000). The concentrator is able to handle two-way communication with all the meters associated to the transformer using low voltage PLC provided by ECHELON. Besides, the concentrators communicate with the Meter Data Management (MDM) receiving and processing reading data using different links, such as cellular network, satellite, wire net (PSTN), etc.



**Figure 6.7: Architecture of AMI system implemented by Enel**

Main features and functionalities of the AMI system include:

- i. Remote reading of energy consumption and power demand
- ii. Elimination of estimated billing
- iii. Multi-tariff structure programmability with possibility of daily, weekly, monthly and seasonal modulation
- iv. Remote change of contractual parameters (i.e. subscribed power demand)
- v. Remote disconnection and reconnection
- vi. Monitoring of service quality (frequency and duration of interruptions in electricity supply) for each individual customer
- vii. Fraud detection and prevention
- viii. Load profiles for active and reactive energy with 1 to 60 minutes sampling time; storage capability of 38 days at 15 minute sampling time for selected customers
- ix. Energy balance per each MV/LV distribution transformer for network planning and to detect fraud areas
- x. Detection of illegal tie-in or unauthorized access to the meter (tamper)

Project key points and emerging lessons can be summarized as follows:

- The decision to replace all existing electromechanical meters by electronic meters with AMI capabilities was a key element to ensure project success.
- Enel is currently evaluating the expansion of the PLC option to involve also medium voltage networks, as a way to simplify the communication system and reduce the big number of its components. Besides, the company is developing applications for demand side management, billing based on load profiles, multi metering (gas, water, district heating, etc.).

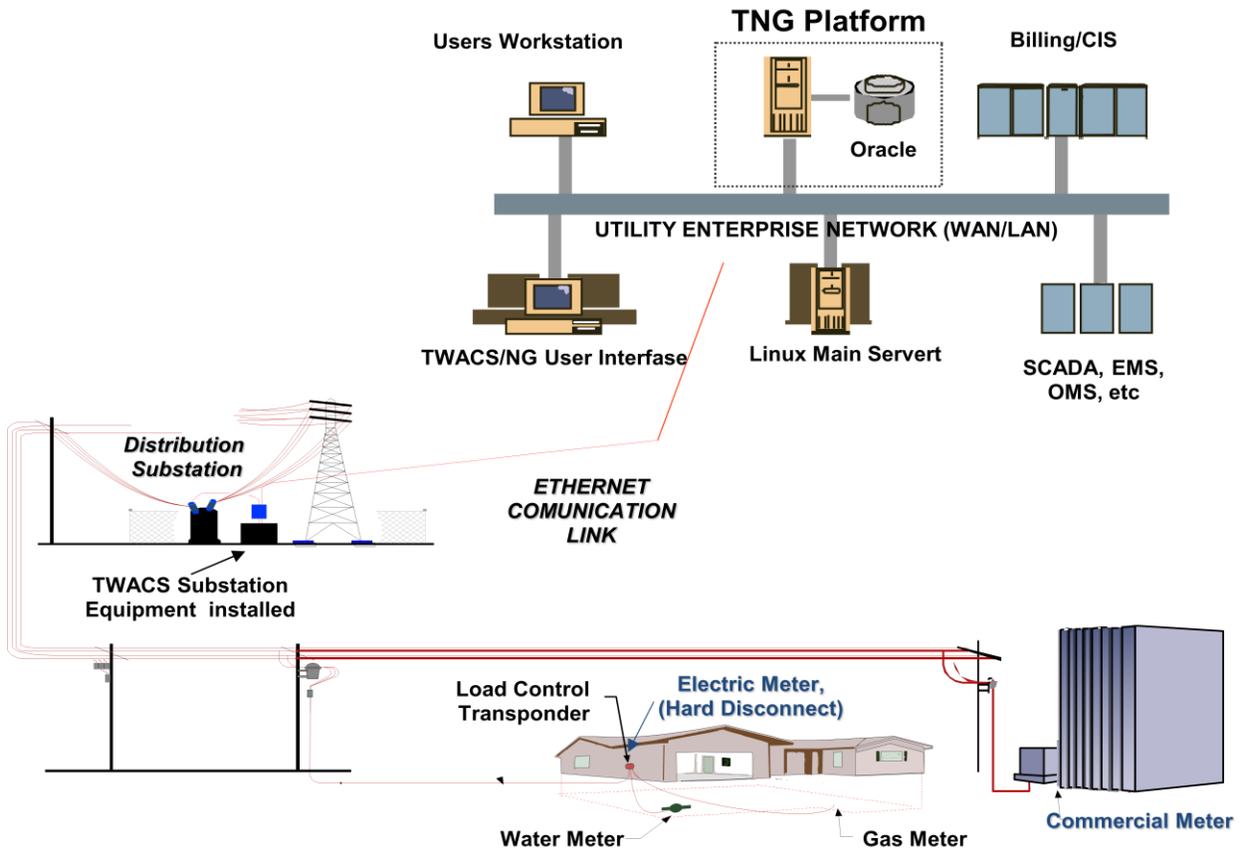
#### **6.4 Pennsylvania Power and Light (PPL) - United States**

Pennsylvania Power and Light (PPL) supplies electricity to 1.45 million customers and has incorporated the AMI system currently managing the largest amount of daily reads in the world. The system processes more than 8 million daily reads (2,680 million annually) with effectiveness over 99%. Some parameters are read every hour, while others daily.

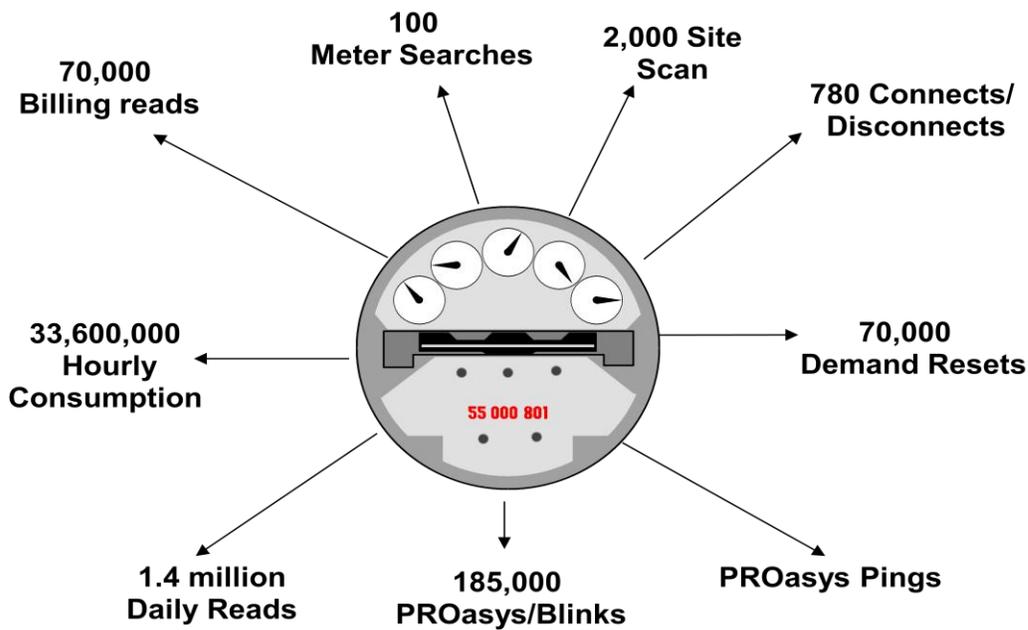
PPL started the process aimed at incorporating the AMI system in the mid 90s. The company initially tested the effectiveness of remote metering of its large customers applying cellular network GSM/GPRS and land lines (600 users), and cellular network CDMA (2,500).

In a second stage started in 2001 the scope of the AMI system was expanded to 1.45 million customers, with the main purpose to eliminate on-site consumption reads for billing. Project total investment costs amounted US\$ 163 million. Payback period calculated considering only the reduction of reading costs is 4.5 years. Implementation period was 2.5 years. Technology used for communications is the PLC TWACS system. It uses medium and low voltage power lines, without the need of data concentrators. Components of the TWAC system allowing signal transmission from the meter through the power network are installed in the distribution substations (315 substations equipped).

**Figures 6.8 and 6.9: Architecture and capabilities of the AMI system incorporated by PPL**



Following figure includes some quantitative features defining capabilities of the AMI system incorporated by PPL



PPL claims that incorporation of the AMI system implied significant improvements in management of the revenue cycle, operations, outages and assets, upgrading of the tariff system (application of time-of-use rates) and customer service in general. Typical AMI functionality being widely used by PPL include: (i) billing reads to support monthly customer billing; (ii) daily reads for use in answering customers questions about usage; (iii) information on peak demand for customer and system use; (iv) special reads (connections and disconnections); (v) interval reads required for billing under time-of-use tariffs; (vi) ability to communicate with meters to facilitate service restoration after storms and other weather events (AMI helps to pinpoint trouble spots in the distribution system); (vii) data diagnostic to assure accurate and reliable reads; (viii) a web-based browser to retrieve meter data; (ix) ability to “ping” meters real-time to avoid truck rolls for no-light calls.

In particular, implementation of the AMI reduced billing errors from 41,000 in 2001 to 2,300 in 2009. Number of complaints related to billing received from the Pennsylvania Public Utility Regulator was lowered by 50 percent in the same period. Billed based on estimated consumption was almost completely eliminated.

Project main issues and emerging lessons are:

- It showed to be crucial for project success the creation of an organizational unit within the company for the specific purpose of developing it.
- The ability to use (retrofit) existing consumption meters was another important positive element.
- PPL recognizes it was a mistake not to incorporate the meter data management (MDM) software from the very beginning of project implementation.

## **6.5. Puerto Rico Electric Power Authority (PREPA)**

The Puerto Rico Energy Authority (PREPA) supplies electricity to 1.56 million customers and has incorporated an AMR system currently managing the largest amount of daily readings outside the United States. The system processes more than 460,000 daily reads (180 million reads annually). Consumption records of 425,000 electronic meters are read daily, while those of 800,000 electromechanical devices are read monthly.

PREPA started the process aimed at incorporating the AMR system in the mid 90s with a pilot project involving 35,000 customers in the municipality of Carolina.

In a second stage started in 1998 the scope of the AMI system was expanded to 1.26 million customers, with the main purpose to eliminate on-site consumption reads for billing. Project total investment costs

amounted US\$ 156 million. Payback period calculated considering only the reduction of reading costs is 5 years. Implementation period was 5 years. Technology used for communications is the PLC TWACS system. Components of the TWAC system allowing signal transmission from the meter through the power network were installed in 285 distribution substations.

Improvements in management of the revenue cycle, operations, outages and assets and customer service in general are comparable to those described for the PPL case. Estimated billing was reduced by more than 95 percent and billing errors more than 96 percent.

Project main issues and emerging lessons are:

- The creation of an organizational unit within the company for the specific purpose of developing the project was a crucial aspect to ensure its success.
- The ability to use (retrofit) existing consumption meters was another important positive element.
- PREPA recognizes it was a mistake not to include the meter data management (MDM) software in the scope of the project. Non-technical losses have been steadily increasing in Puerto Rico in recent years. PREPA noticed that the software provided by TWACS is adequate to manage reads for billing purposes (the initial objective of the project) but inappropriate to monitor consumption with the periodicity required to detect and correct abnormal situations. It is perhaps the opposite case to that of NDPL in India: optimized communication infrastructure, but software inadequate to combat non-technical losses. Now PREPA is moving urgently to incorporate state-of-art MDM. The high number of electromechanical meters (more than 800,000) also affects the effectiveness of the remote metering system to reduce losses.

## **6.6 Edesur (Dominican Republic)**

EDESUR is a state owned electricity distribution company serving more than 400,000 customers in Santo Domingo, the capital of the Dominican Republic, and surrounding areas. Performance of the power sector in the country has been very poor, with total losses above 30 percent of generated amounts of energy and permanent power shortages. Less than 50 percent of consumers are supplied 24 hours every day, and power outages are very frequent.

At the beginning of 2005 Edesur started planning an AMI project, aimed at achieving a sustainable reduction of its very high non-technical losses. Initial scope of the project was 7,400 large industrial and commercial consumers (2,500 in high and medium voltage, 4,900 in low voltage) and 18,100 large low voltage residential customers. Total investment was US\$ 7.2 million and the project was implemented in 2 years. Total losses were reduced by close to 7 percentage points after remote metering was installed, determining a payback period of 3.5 years.

Technology used for communications is the TWACS PLC system, with components installed in 43 distribution substations. Functionality of the system is the same described for the PPL and PREPA cases.

As most of the existing meters were of the electronic type, they could be used as components of the remote metering system. Besides, integration between AMI and the commercial management system for billing purposes was successfully developed.

On the negative side, Edesur made the same mistake than PREPA, as it did not incorporate a MDM, and just uses the basic software provided by TWACS, which has been designed to process monthly reads for billing purposes. This situation evidences the critical importance of corporate governance in management of any company, particularly in the utilities segment. The PREPA system was designed to manage consumption reads for billing, which is the typical application in developing countries. As total losses in the company were acceptable at that time, the decision seems reasonable. Now PREPA notices that sustainability of that acceptable condition was not granted and needs to prepare itself to combat losses.

The situation of Edesur is completely different. The company faces enormous financial deficits due to high non-technical losses. AMI was supposedly implemented to address this issue, but some failures in its design (lack of the MDM) limited its effectiveness in its application. The main problem is that Edesur top management failed to take any initiative to promote the incorporation of an MDM during more than 3 years. Besides, it took other decisions that evidence company's poor corporate governance. The TWACS system showed to be unable to transmit the signal from the meters to the company's server in the cases of the 2,500 largest medium and high voltage customers with indirect metering equipment. This is due to the fact that the capacity of the voltage transformers of the indirect metering system must needs to exceed a certain threshold, a condition that is usually met in developed countries but not in the Edesur case. Instead of promoting an alternative solution to the problem, such as the installation of individual GSM/GPRS modems, the company restored on-site reading for those customers. This implied not only leaving unprotected the revenues related to the sales to a critical segment, but recreating the potentially dangerous conditions eliminated by the initial application of AMI. A change in top management of Edesur holding company in recent months is making possible to take diligent action to implement the right decisions: installation of individual cellular modems for the 2,500 largest consumers and incorporation of a state-of-art MDM system.

## **7. The way forward**

### **7.1. AMI for sustained reduction of non-technical losses and revenue protection**

In the short term, applications of AMI in World Bank country clients should be focused in cases of electricity distribution companies with high values of non-technical losses. Implementation of AMI for metering, reading and monitoring consumption of large customers in all voltage levels should have maximum priority for those companies. As described in Section 5, **it should start by high and medium voltage customers, but immediately extend to largest low voltage consumers.** There are several well proven technological options available with infrastructure requirements that are met even in the poorest developing countries. Positive impacts on the financial health of the company derived from sustained recovery and protection of revenues related to sales to that critical segment are huge and can be achieved in short periods. Besides, transparency and corporate governance in company's management will be significantly enhanced.

The lessons emerging from the application of remote metering to large consumers described in Section 5 define the main elements to be taken into consideration to ensure the successful implementation of a well designed AMI project for large consumers in all voltage levels:

- The project should be considered as a specific initiative, fully separated from the company's regular operations. Top management should allocate maximum priority to its successful design and implementation.
- The distribution company should create a "Large Customer Department (LCD)", responsible for managing all aspects of its interaction with large customers (metering, billing, collection, attention of claims related to quality in electricity supply). Its manager must be an expert with wide professional experience in the commercial management of large customers. Organizational structure and operational procedures of LCD should ensure that each large consumer receives personalized attention from a single "contact person" in the company, who should be responsible for addressing all the issues in the interaction, taking care of all the internal arrangements needed for that purpose.
- A "Metering Control Center (MCC) should be created within the LCD, with the specific assignment of operating the remote metering system for large consumers. Staff of the MCC should be young engineers, trained by the AMI system provider. Their main tasks should be ensure permanent reliable and timely reception of data provided by the system; carry out systematic analysis of the data, in particular alarms, changes in daily consumption, etc.; implement corrective actions that may arise as a consequence of the analysis, such as field inspections to customers' premises by crews directly reporting to the MCC (fully independent from those involved in field inspections to other customers); follow-up of the results of the inspections; permanent update of the database used by the system.
- A "Meter Data Management (MDM)" intelligent software making possible efficient performance of the MCC must be incorporated in the initial phase, as it is a critical component of the AMI system. Main functionality and features of the MDM must be focused on periodic monitoring of consumption for detection and correction of theft and other sources of non-technical losses. Software packages designed to

manage remote meters reads for billing purposes (typical in developed countries) are in general not adequate to address loss reduction.

- The distribution company must define and effectively implement organizational arrangements for proper maintenance of all the components of the AMI system and ensure its sustainable good performance. Incorporation of the system should be considered by the distribution company as **provision of metering services**, more than supply and installation of equipment and software. The supply, installation, commissioning and maintenance of all the components (hardware and software) of the AMI system during a 2 to 5 year period should be contracted with a special purpose group, formed by companies providing skills in meter manufacturing and installation and MDM software. All the field activities related to installation and maintenance of the components of the AMI system will be outsourced to the contractor, who will become fully responsible for their proper performance. The electricity company must retain for itself the actually core functions of processing all the data provided by the AMI system, which include billing, detection and correction of any abnormal condition, load management, planning, etc.

This approach for incorporation of the AMI system helps to ensure its sustainable operation, minimizing the risks of outages due to failures in some of its components. The contractor will be fully responsible for the design, implementation and reliable operation and maintenance of the metering system as a whole, as well as each and all of its components. He will need to evaluate all the aspects required to ensure a reliable performance of the AMI system, as described in this report, and specify the most appropriate components accordingly (in particular the best technology to be used for communications, the meter data management software, etc.).

The utility will prepare a set of minimum **functional specifications** of the AMI system and require market vendors to join in special purpose groups providing skills in meter manufacturing and installation and MDM software and present detailed technical proposals fully meeting those functional specifications. A sample specification, based on a document prepared in 2006 by the Ontario Energy Authority, Canada is attached as Annex 3. Although most of the AMI systems currently available in the market are compatible with almost every electronic meter, fulfillment of this condition should be checked in the evaluation of the technical proposals received.

Metering services will be paid per installed and commissioned point and monthly received reads. Standards on performance of the AMI and a regime of penalties to be applied in case on non fulfillment by the contractor must be included in the functional specifications.

This approach is being adopted in two large AMI projects financed by the World Bank. One of them involves DHBVN, a state-owned electricity distribution company in the State of Haryana, India. AMI will be implemented for all consumers with demand above 10 kW, including remote disconnection and reconnection for those in the interval 10-30 kW and remote metering in distribution transformers. Project is currently under execution (functional specifications of the AMI system being elaborated by DHBVN).

The second case refers to six affiliate companies of the Brazilian group Eletrobrás, having the central government as the major shareholder. AMI will be installed to all consumers with monthly consumption above 600 kWh. In both cases the companies face high non-technical losses, and, by focusing on the large customer segment, the projects are expected to achieve sustained reductions in short periods. Financial rates of returns are very high in both cases. But economic rates are also very attractive, as it is expected that part of the currently unmetered consumption will become reduced demand, with related economic benefits to the country due lower electricity generation.

As mentioned in Section 5, it is not unusual in some World Bank country clients the case of poorly performance state-owned utilities whose top management is reluctant to apply AMI to their large consumers, arguing this a closely monitored sector, without non-technical losses. In those situations, the need to ensure sustainability on time of that supposedly good condition (the case of CEMIG) should be used as a first argument to overcome that resistance. As this is unlikely to be effective if systematic under-billing of large consumers involves (or at least tolerated by) top management of the company, a more realistic option should be to get the support of the Ministry of Finance, usually very concerned by the financial contributions it is obliged to provide to poorly performing power companies, just to keep that bad condition.

The eventual need to apply AMI to regularize supply to low-income areas with high losses should be analyzed as described in section 7.2 5 below. But it should never be the first stage in the process. The distribution company could include in the scope of the first phase (AMI for its large customers in all voltages) the installation of AMI in DTs supplying those areas. This “wholesale metering” will make possible to quantify current losses in supply to those areas and evaluate the economic feasibility of AMI application. It is quite usual to find in some developing countries (particularly in South Asia) areas inhabited by extremely poor people, where consumption (regular or not) is actually very low. Although losses can be expressive in percentage points of supplied energy, their amount in physical units is usually irrelevant to explain high total non-technical losses companywide. Corrective action should never begin in those areas.

## **7.2. The management improvement plan for electricity distribution utilities in developing countries**

Any plan for reducing losses in the future should make proper use of AMI, combined with management actions and investment. Synergy in the implementation of those actions can be maximized if they are assembled together as components of a management improvement plan (MIP) of an electricity distribution utility, the five key components of which are described below.

### 7.2.1. Component 1: Achieving “zero non-technical losses and 100 percent collection” in electricity supply to large consumers connected to high- and medium-voltage networks

*Step 1: Create a large customer department as an organizational unit within the commercial department*

A large customer department will be responsible for managing all aspects of a utility’s transactions with large customers. Its manager must be an expert with wide professional experience in the commercial management of large customers.

*Step 2: Design and implement a detailed field assessment on the current situation of all consumers supplied by high-voltage and medium-voltage lines, the largest low-voltage customers, and potential irregular users in these categories.*

The conditions of large consumers in all voltage levels (defined by a minimum value of monthly consumption) must be accurately known. A comprehensive field assessment should be made based on visits to all points of supply. At each site being visited, the crew must check the condition of electric connection (wires, meter, etc.), determine actions to be executed for technical regularization of the connection, verify the commercial condition of the customer (active customer, etc.).

*Step 3: Define and execute a plan to regularize supply where needed.*

Based on the conclusions of the assessment executed in step 2, a plan aimed at regularizing all points of supply to large consumers must be designed. Regularization is not limited to the condition of the physical connection for electricity supply but includes commercial aspects. The distribution company should sign a new supply contract with each large consumer where shortcomings in metering, payment, or both, have been found.

A new database for those consumers should be created and regularly updated. The large customer department will have commercial agents. Each agent will manage all aspects, technical and commercial, of the contract between the distribution company and a group of large consumers. Each large consumer will be informed by the agent in charge that he will receive personal attention and will be encouraged to call the agent for any issue related to the service provided by the distribution company. In particular, commercial agents will be responsible for close monitoring of technical and commercial conditions of the supply to each large consumer on his list.

*Step 4: Implementation of AMI in all points of supply to regularized large customers*

As described in Section 6.1.

*Step 5: Define and put in practice operational procedures for periodic systematic monitoring of electricity supply to large customers and for taking immediate corrective action for any irregularity detected.*

Regularization of large consumers does not end with the execution of activities described in step 4. Stopping at step 4 is a serious mistake made by many utilities. Periodic and systematic follow-up of all regularized large consumer is a crucial task. Until AMI is implemented, it implies that the crew in charge of regularization visits customers periodically and checks that the situation remain normal (no clandestine additional connections or tampering with metering detected). Once AMI is implemented, inspections can be executed once a month or every time the data received daily show any abnormal patterns.

#### 7.2.2 Component 2: Incorporation of a new CMS and related procedures for commercial activities.

In order to achieve sustainable good commercial performance, the distribution company must incorporate a state-of-the-art commercial management system (CMS) allowing proper execution and monitoring of all activities related to: commercial cycle (regular metering, billing, and collection); dealing with customers at commercial agencies or by phone (call centers); disconnection and reconnection of electricity supply related to commercial debts; connection of new customers.

Incorporation of the new CMS requires building, maintaining, and regularly updating a reliable customer database.

#### 7.2.3 Component 3: Incorporation of a new incidence resolution management system and related procedures for addressing customer claims caused by poor quality of electricity supply.

Efficiently performing distribution companies use an incidence resolution management system (IRMS), which is another IT application not directly related to loss reduction but which improves service quality. High service quality gives incentives for on-time payment of bills and helps reduce tampering with metering and damage to equipment belonging to the utility. IRMS is a highly effective tool for dealing with customers' complaints and improving the quality in electricity supply. It allows the company to minimize time elapsed between receipt of the claim and restoration of regular electricity supply and, at the same time, maximize efficiency in the execution of the activities that the company must perform for that purpose. Conceptual design of IRMS is based on setting a link between each point of electricity consumption and the electric networks involved in the supply. This allows quick identification of the potentially faulty components of the networks related to a claim presented by a customer and sending the operational crews straight to those installations. This enables proper management of claims related to faults affecting a large number of consumers.

Effective implementation of the IRMS requires building and regularly updating a system database. Through a comprehensive field assessment, based on physical visits, network assets for supplying each customer are identified. These links between customers and network assets are the components of the IRMS database.

#### 7.2.4. Component 4: Actual application of new procedures and rules for customer service

Incorporation of the new CMS must be complemented with the formulation and application of new operational procedures. Activities to be re-engineered include: commercial cycle: metering, billing (including delivery to customers), and collection; detection and regularization of fraud and unmetered connections; disconnection and re-connection of customers related to debts and/or fraud; dealing with customers at commercial offices; dealing by phone with customers reporting disruptions to electricity supply and other commercial matters through call centers.

Operational procedures for commercial activities must be developed at the same time as, and in full coordination with, the implementation of the CMS which is the main tool supporting execution of those operations.

Reengineering of commercial activities include, among other aspects: metering; billing; delivery of bills; collection; detection of fraudulent activities and regularization of unmetered connections; disconnection of customers on account of debts and/or fraud and subsequent reconnection; establishing a call center for customer service

#### 7.2.5- Component 5: Regularization of supply to areas with high non-technical losses

High technical and non-technical losses are usually linked to a significant number of irregular connections to low-voltage lines (which are typically damaged as a result), customer connections in poor condition, faulty or non-existing consumption meters, etc. Those damaged assets must be replaced by new ones to achieve a sustainable regular electricity supply. It is necessary to conduct a detailed field assessment on the physical condition of those networks and identify: low-voltage lines and customers connections that need to be renovated; new consumption meters to be installed (both to replace damaged devices and to place new ones at previously unmetered points of supply); replacement and installation of new switchgear equipment (automatic breakers, isolators, etc.) needed to optimize network configurations and operation.

However, the technical solutions to be applied for renovation of low-voltage lines, customer connections, and metering devices must be defined and implemented according to the socio-economic characteristics of the users, as described in the following paragraphs.

- Regular (“manageable”) areas

For those consumers located in areas where the utility can perform operations without significant constraints, the solution involves improving electric networks and installing electronic consumption meters, allowing remote metering, at each customer connection and also at the distribution transformer supplying a group of consumers. This enables fast detection of irregular connections and fraud, enabling immediate corrective actions to be taken at the site and thus promoting consumers discipline in electric service. The concept supporting this approach is to avoid investments in network assets as much as possible and concentrate in remote metering devices because, once detected, fraud and theft can be eliminated with operations at the site. Comprehensive experience in almost all Latin American reforming

countries show that consumer discipline is achieved in quite a short time if those irregular consumers become aware that the utility is able to make fast detection and take corrective action on fraud and theft.

- “Unmanageable” areas

For those consumers located in areas where the utility cannot perform regular operations due to high crime or other constraints, regularization will be based on the “Rede Ampla” approach (medium voltage distribution + AMI) described in Section 6.1 or similar options.

### **7.3. Creating the conditions for proper evaluation of the viability of AMI driven demand side management programs**

As stated in Section 5, a pricing system for electricity service providing users with the right signals on actual costs of supply is an absolutely critical condition to promote efficiency in consumption.

Reform processes in the power sectors of some developing countries carried out in the 90s and initial years of the 21<sup>st</sup> century allocated low priority to actions aimed at planning the sustainable expansion of the power sector. As a consequence, the institutional capacities of the government agencies in charge of those actions were deteriorated. The new global scenario, characterized by high prices of energy resources and conversion equipment, together with the increasing importance of aspects such as security of supply, environmental constraints and the impacts of climate change, determines the crucial need to develop planning studies aimed at identifying options available for the country to expand its power sector and building-up scenarios to be evaluated. Total costs of efficient supply arising from the technical and economic evaluation of each scenario, and their variation in time of day, will determine the effective viability of DSM programs.

Planning studies should be complemented with the review and upgrade of existing tariff systems to ensure their charges and rates actually reflect total costs of efficient supply, as well as the implementation (or adjustment, if already existing) of social safety nets aimed at protect low income consumers.

Thus, it may become necessary to support some country clients in their efforts to: (i) strengthen the capacities of the agencies responsible for planning the expansion of the power sector; (ii) identify the best institutional arrangements to implement the outcomes of the planning studies; (iii) set and periodically adjust electricity tariffs in order to reflect total costs of efficient supply, eventually complemented by social safety nets.

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