

## Cost-benefit analysis in the modernization of the residential low-voltage measurement system in Mexican territory

### Análisis costo-beneficio en la modernización del sistema de medición en baja tensión residencial en el territorio Mexicano

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#### Abstract

The modernization of the measurement in low residential voltage has caused inconveniences to the consumers of the CFE (Comisión Federal de Electricidad). This research aims to identify advantages and disadvantages offered by the implementation of electronic meters in the Mexican territory. The electronic measurement system offers precision reliability and control of user consumption. However, electromechanical meters have up to 5% error in the measurement. A cost-benefit analysis in the modernization of the measurement was carried out considering the socioeconomic, cultural and service environment to identify the advances offered by the modern measurement system concerning the one implemented in the country. The results determined that both systems are vulnerable, due to technological progress. The electronic cards could be reprogrammed electronically without altering their physical appearance which generates that the anomalies to the system of measurement by the company of supply are not detected. On the other hand, the costs incurred for modernization by the Mexican government and the supply company may not yet be fully amortized, and the new measurement system could cease to be reliable before its obsolescence.

#### Modernization, Cost-Benefit, Low Voltage

#### Resumen

La modernización de la medición en baja tensión residencial ha causado molestias a los consumidores de la CFE (Comisión Federal de Electricidad). Esta investigación tiene como objetivo identificar ventajas and desventajas que ofrece la implementación de medidores electrónicos en el territorio mexicano. El sistema de medición electrónico ofrece precisión confiabilidad and control del consumo del usuario, sin embargo, los medidores electromecánicos presentan hasta un 5 % de error en la medición. Un análisis de costo beneficio en la modernización de la medición fue llevada a cabo considerando el entorno socioeconómico, cultural and de servicio para identificar los avances que ofrece el sistema de medición moderno con respecto al implementado en el país. Los resultados determinaron que ambos sistemas son vulnerables, debido al avance tecnológico. Las tarjetas electrónicas podrían ser reprogramadas electrónicamente sin alterar su apariencia física lo cual genera que no sean detectadas las anomalías al sistema de medición por la compañía de suministro. Por otra parte, los costos realizados para la modernización por el gobierno mexicano and la compañía de suministro posiblemente no serán aun amortizados en su totalidad, and, el nuevo sistema de medición podría dejar de ser confiable antes de su obsolescencia.

#### Modernización, Costo-Beneficio, Baja Tensión

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## Introduction

The CFE together with the Mexican Federal Government has implemented a modernization program for low voltage measurement in order to have better control of consumption and an improvement in the finances of the supply company (Cruz S.N., 2016).

The objective is to identify the advantages and disadvantages offered by the implementation of electronic meters in Mexican territory.

The electronic measurement system offers precision reliability and control of user consumption, however, electromechanical meters have up to 5% error in measurement. A cost-benefit analysis in the modernization of the measurement was carried out considering the socioeconomic, cultural and service environment to identify the advances offered by the modern measurement system with respect to the one implemented in the country. (Diario Oficial De La Federación and CFE, 2017).

In 2012 an open call was launched for a tender for the project called "modernization of low-voltage measurement". As a result of this process, a leading company in the electrical industry won two contracts, the first of which consisted in the installation of 30 million 428 thousand 665 electronic measuring equipment with a cost of 12 thousand 250.4 million pesos and the date of settlement 2014.

The second contract was of 4 million 321 thousand 974 teams, with a cost of 6 thousand 890.6 million pesos which had to be carried out in the period of 2014-2016 (Cruz S.N., 2017).

The total project of the modernization of the measurement in the country has a total of 34 million 750 thousand 639 digital power meters with a total cost of 20 thousand 167 million pesos. In addition to this, the maintenance and operation services for these equipment were contracted for a period of 33 years with a cost of 1 billion 131 billion pesos (Cruz S.N., 2017).

For the year 2017 the company that won the tender reports that they had had an advance in the implementation of the measurement of 73.77% for the first project and 21.5% for the second.

The company reports that it did not reach the stated objectives because it faced problems such as the opposition of users to the change of the measurement system, especially in the states of Hidalgo, Puebla, Morelos, Veracruz, Tabasco, Yucatan, Chihuahua where in response to the change of meters were generated riots, rallies and in some cases were ripped and thrown in front of the corresponding government offices (Cruz S.N. and Lazáro, 2017). This is due to the fact that users attribute that these systems are not reliable in the measurement, and that rumors have been generated that they are previously programmed to increase consumption. (Cruz S.N. and Lazáro, 2017). On the other hand, it is believed that the main cause of the unacceptance of these systems is that electronic meters are prepaid and in Mexico, users are accustomed to the fact that the company finances the energy supplied until the cutoff date. However, all the equipment installed by CFE is tested by the laboratory equipment and materials (LAPEM) and they have gone through a process of calibration and metrology that ensures their proper functioning in laboratory and field. (Laboratorio de Pruebas Equipos and Materiales "LAPEM" 2017). On the other hand, the supplier company in order that users accept the change has implemented a program so that electronic measurement systems have the possibility of belonging to the prepaid or payment system at the cutoff date. (Cruz S.N., 2017).

An engineering analysis of the modernization of measurement systems evaluated the pros and cons of this system, finding that resistance to change is due to external factors that obey other interests (Political, social, cultural and economic) and not precisely related to technological development (Cruz S.N., 2016). On the other hand, no measuring system escapes from being altered by external means, so it is considered that these have a pre-established safety by the manufacturer and that some world powers follow this trend in the measurement (Mendieta, 2015). However, a total opposition to the change puts the supplying company in a technological backwardness, which in agreement with the Federal Government provides the subsidies in low tension and that in the worst scenarios, supplying the service by a foreign company could generate new reforms to the subsidies or even exterminate them (Cruz S.N., 2016).

## Legal framework

According to the Energy Regulatory Commission, for the second time in a row, the Official Mexican Emergency Regulation NOM-EM-007-CRE-2017, for electrical energy measurement systems with their respective specifications and test methods for multifunction meters and transformers instrument, with number of agreement A / 033/2017, which establishes that on the occasion of the Decree by which various provisions of the Political Constitution of the United Mexican States on Energy are amended and added, published in the Official Gazette of the Federation (OGF) on December 20, 2013, the Congress of the Union issued the Law on the Electricity Industry (LEI) and the Law of the Coordinated Regulatory Bodies on Energy Matters (LCRBEM), both published on August 11, 2014 in the same means of dissemination, repealing the Public Electricity Service Law and the Law of the Energy Regulatory Commission (NOM-EM-007-CRE-2017).

According to article 40, section IV, of the LFMN, the official Mexican standards will have, among others, the purpose of establishing the characteristics and / or specifications related to the instruments to measure, the measurement standards and their methods of measurement, verification, calibration and traceability (NOM-EM-007-CRE-2017).

The elements of the electric power measurement system must comply with what is stated in this Official Mexican Official Standard of Emergency with the operating conditions of the electric network, being focused on the safety of the elements that make up a measurement system according to the Official Mexican Standard NOM-001-SEDE-2012, of electrical installations.

In its third section the energy regulatory commission establishes the administrative support, the orientation to make transparent to the citizenship the operative and administrative activities of the energy regulatory commission with the purpose of finding a competitive and sustainable energy market development for the benefit of the society in order to generate certainty that encourages productive investment, fostering healthy competition, promoting adequate coverage and security in the electricity supply.

Based on a legal framework of the Political Constitution of the United Mexican States (OGF 05-02- 1917), and in laws such as: Law on Coordinated Regulatory Bodies in Energy Matters, Electricity Industry Law, Energy Transition Law, Federal Law on Consumer Protection, to mention a few (Comisión Reguladora de Energía, 2017).

On the other hand, we have the Code of Conduct of the Energy Regulatory Commission in order to guide the performance of the Public Servants of the same, with the purpose that in the exercise of their functions they assume a full and honest attitude, in adherence to the institutional values of rectitude, honesty, impartiality, respect and transparency, taking into account the Internal Regulation of the Energy Regulatory Commission (OGF 04-28-2017) and the Decree by which the Energy Sectorial Program 2013 is approved -2018 (OGF 13-12-2013) where the strategy is to promote the sustained growth of productivity in a climate of economic stability, as well as the efficient use of productive resources, strengthening the business environment, and establishing sectoral policies for boost economic development. There are several Plans and Programs such as: National Development Plan 2013-2018, Sector Energy Program 2013-2018, Program for the Development of the National Electric System 2015-2029, all of them under the guidelines of the Energy Regulatory Commission (Official Gazette of the Federation, 2013).

The Energy Reform approved on December 20, 2013 by the Congress of the Union was the trigger for the modernization of the energy sector without privatizing the Mexican State public companies engaged in the production of electricity. The reforms have as objective and fundamental premises to modernize and strengthen without privatizing the Federal Electricity Commission as a 100% Mexican productive company allowing the nation to exercise exclusively the planning and control of the national electrical system having a competitive system that allows to reduce the prices of electric power, without neglecting international standards of efficiency, quality, transparency and reliability of supply in accountability, effectively combating corruption in the energy sector and promoting greater investment to boost development in the country. (Energetic Reform, 2013).

A comparison of electricity prices in the Mexican sector represents an average of 25% more than in the United States, considering the subsidy from the Federal Government already included. If this were not taken into account, the price of electric power would be up to 73% higher, constituting a brake on the Mexican economy, given that the essential input for residential, industrial, commercial and service activities is electricity.

The CFE reported energy losses in Mexico of about twice as much as the countries that make up the Organization for Economic Cooperation and Development (OECD). On the other hand, statistics of the CFE establish billing losses of up to 15% due to different problems related to the measurement (lack of access to the meter, erroneous measurements, alteration of the measurement system) which places the company in a state critical since international business statistics establish that no company can support more than 21% of losses without presenting financial problems (Energetic Reform, 2013).

The Energetic Reform has the Constitutional Article 27 that establishes that the planning and control of the national electrical system, as well as the transmission and distribution of electric power correspond exclusively to the Nation and in the Constitutional Article 28 establishes that the planning and control of the system national electricity, as well as the public service of transmission and distribution of electricity are exclusive areas of the State for the benefit of Mexicans, in terms of generation and commercialization of electric power. However, the constitutional reform established at the end of 2013 allows the opening of private investment (Energetic Reform, 2013).

Considering that the National Energy Control Center, which before the reform was part of the CFE, is transformed into a decentralized public body in charge of the operational control of the national electricity system (SEN), it assumes responsibility for the monitoring of production vs billing.

For this, the energy coming from clean sources belonging to the sustainable development programs must be considered (Constitutional Reform in Energy Matter, 2013).

## Methodology

This research has a quantitative, qualitative and mixed approach applying a set of systematic, critical and empirical processes. Using the quantitative approach was carried out a cause and effect analysis in a sequential, deductive process with an objective reality analysis predicting a hypothesis for the control of this research. Regarding the qualitative approach, the phenomena related to the problem were explored in depth, proposing possible results of the data obtained under an inductive process recurrent to the subjective reality; contextualizing the phenomenon for different sources of research such as: written materials (books, newspaper articles, notes) as well as web pages. The definition of the scope of the research carried out quantitatively must be taken into account by combining the descriptive, correlational and explanatory scopes considering the phenomenon studied and its components, offering a relationship between variables with a sense of understanding that is easier to understand. The design of longitudinal non-experimental quantitative research is needed, because changes over time were analyzed observing this phenomenon as they occur in their natural context, and then analyzing it based on observations of existing situations (Hernández, 2010, p.275).

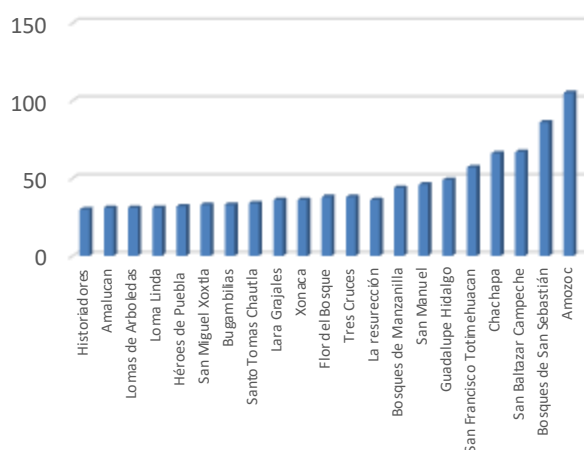
## Population and Sample

The data collection was done through the qualitative and quantitative approach applying the deductive logic from the general to the particular, from the laws and theories to the data preceding the collection. Pretending to generalize the results of the research, we had a descriptive analysis of the data according to the variables, explaining the movements and changes processed by the database. The results obtained through the mixed approach involve combining the quantitative approach with the qualitative one, resulting in tables, statistical models verifying the feasibility criteria (Hernández, 2010, p.275).

Our population includes the entire Mexican Republic with more than 123 million 518 thousand 270 inhabitants until 2017 (Sagarpa, 2018). Once the unit of analysis is defined, the population is delimited taking a subgroup of the total population, from which the data was collected.

Non-probabilistic samples were taken as references in the Bosques de San Sebastián Housing Unit located in the Puebla Oriente distribution area (POA). The energy generated for this zone comes from the Laguna Verde nuclear power plant located in the state of Veracruz and the San Lorenzo Potencia combined cycle plant in Puebla, which supply the Puebla Dos Mil power substation, while the Chicoasén and Malpaso belonging to the state of Chiapas supplies the Tecali power substation. Both substations are supplied through 440 kV transmission lines, after the power substations (Tecali and Puebla Dos Mil) and through 115 kV lines are transmitted to the distribution substations that make up the POA. The study area is supplied by the Bosques substation, which is one of the 13 substations installed in the POA, in charge of reducing medium voltage voltages in either 34.5 or 13.5 kV lines and these in turn through transformers are reduced to low voltage (127 or 220 volts) to be sold residentially. (CFE, 2017).

According to CFE billing reports belonging to the study sample until August 2017, there were a total of 6,118 residential customers that have an analog measurement system. The POA has 8 branches in which were received the disagreements of the colonies and populations that are within the jurisdiction. To establish the sample, it was necessary to consult the nonconformities presented by each thousand users (IMU). The sample was selected based on the IMU statistics in the POA for the low voltage service, identifying that the Forest Unit of San Sebastián registered a greater number of nonconformities. (CFE 2017).



**Graphic 1** IMU for CFE colonies

Source: Self Made

## 1 Plan for the modernization of the measurement system

The CFE intends to change 4000 electromechanical meters by digital meters in the U.H. Forests of San Sebastián. A technical and economic proposal that complies with the general provisions regarding acquisitions, leases, contracting of services and execution of works by its Productive and Subsidiary Companies under the specifications of the 30 fraction V provision, complying with the stages and deadlines convened in the open contest, in order to dictate a winner who will carry out the modernization works of the digital meters (Federal Budget Law and Fiscal and General Public Debt Responsibility, 2006).

## 2 Estimated costs for the modernization of the measurement system

Taking into account a previous analysis of the modernization of the measurement system, it was necessary to evaluate possible alternatives that can be presented in such a project with the sole purpose of giving the best solution and being able to take the most convenient decision to guarantee the viability and objectivity, between Cost, quality and execution time.

To determine the cost it was necessary to call open competitions, as well as offers and auctions for the contracting of the service of modernization of the measurement system to be able to choose the best option in accordance with the general provisions of CFE. (Cruz S.N. and CFE, 2017).

It has the purpose of making the analysis as accurate as possible, for this it is inevitable to consider inputs, returns and the number of workers needed to carry out this project. A calculation memory was made to obtain the necessary technical information and the costs of the project, optimizing its execution.

This project is integrating the cost through the unit price method, defining activities, labor and inputs needed to make the change of 4000 meters. Each of the concepts is specified, the duration of each activity based on the returns with respect to each activity, however, only the resulting values were taken to be presented in this work table 1. (Cruz S.N. and CFE, 2017).

Unit Cost without Accessories		Unit cost of accessories	
Unit Price per meter change	\$ 188.74	Unit Price Digital Meter	\$ 1,202.33
		Unit price safety rings	\$ 23.50
		Unit price bolt seal	\$ 1.52
Meters to change	4000		
A) Project cost without accessories	\$ 754,970.08	B) Total cost of accessories	\$ 4,909,400.00
C) Project cost (A + B) without VAT and Finiquito:			
\$ 5,664,370.08			
D) VAT 16%	\$ 906,299.21		
F) Settlement of workers	\$ 0.00		
Total project cost (C+D+F)	\$ 6,570,669.29		

**Table 1** Supplies needed to change digital meters

Source: Self Made

## Results

### Estimated time the investment will be recovered

A domestic user of the U.H. Forests of San Sebastian, consumes 182.8 kWh monthly average with an approximate cost of \$ 1.52 MXN per kWh, however, studies carried out in electromechanical meters report up to  $\pm 5\%$  of error in the reading of the total consumption of the user per month, which corresponds approximately to a range of 10% (18.28 kWh) on average representing a loss of \$ 27.8 on average per customer on a monthly basis (CFE, 2017).

However, the digital meter due to the technology with which it was manufactured reports errors of up to  $\pm 0.5\%$  of the measurement which corresponds to approximately 1%, of total error (1.82 kWh) per customer per month, meaning \$ 2.77 MXN and representing 9.9% with respect to the losses generated in an electromechanical meter.

If it is considered that the losses in an electromechanical meter represent 100%, which will have to be paid in the billing and on the other hand, the losses generated by a digital meter would save 90% of this amount in the billing payment.

Therefore, the change of electromechanical meters by digital, based on the "2017 population census" establishes that 65.4% (4,000 meters) of UH Bosques de San Sebastián customers still have the electromechanical meters of 6,118 total customers reported by the CFE until August 2017. (CFE, 2017).

This represents approximate energy losses of 36,560 kWh per month (438.72 MWh per year) in that area, which are not billed for using the electromechanical measurement system which represents \$ 55,571.2 MXN monthly, therefore \$ 666,854.4 MXN per year.

The modernization of the meters of this project in the U.H. Bosques de San Sebastián will cost \$6,570,669.29 MXN. If you consider the annual loss that would be generated from the meters to change, this amounts to \$ 666,854.4 MXN. Given this scenario, the investment would recover in approximately 10 years (present value 2017), because the losses generated by the electromechanical meters would represent approximately the cost of the project. (This study is due to official statistics until December 2017, because 2018 statistics are not yet reported by government agencies).

The U.H. Bosques de San Sebastián served as a fundamental basis to have an estimate of the total amount required to carry out the implementation of the measurement modernization at the national level. The CFE reported that it has 43,059,956 low voltage electric power users throughout the country in the Mexican territory, with this data we can make an escalation of the final price that this modernization will have, shown in the following table.

Average cost in the modernization of 4000 meters	\$ 6,570,669.29
Average cost in the modernization of 43,059,956 meters	\$ 70,733,179.5076

**Table 2** Inputs needed to change digital meters nationwide

Source: Self Made

The first hirings assigned since 2012 must be taken into account, which were mostly tendered by the IUSA company. These were divided into two contracts with a total of 34 million 750 thousand 639 meters throughout the country with a settlement of total installation by the end of 2016. However, this was not achieved and in June 2017 an advance of 73.77% and 21.5% was reported, which led to a new estimate of the total number of meters to be changed. Which were subsidized by the federal government in conjunction with the CFE, although it is well known that the cost of the work published over time will be covered by users according to current regulations.

## Discussion of results

The users reply that in their assessment after the transition of the change of meters, the digital meter increased the economic amount of the energy consumption to be paid with respect to the historical amount made in electromechanical meters (Lázaro, J. 2018).

Therefore, the reaction is immediately inconformity, arguing that it is a theft by the "unjustified" increase and do not consider that the possible causes of economic growth are due to: change of tariff according to consumption, supply and demand, increase in cost per kWh according to the season of the year, gradual payment of the cost of the meter.

For this reason users with the analog measurement system are also affected in the increase of consumption based on these parameters.

A great unknown of the user of the CFE is to know if at the end of the day the meters will be paid by the consumer and these will be the property of the user or CFE.

The previous regulations established that the meter was paid by the user that by law this is part of the infrastructure of the CFE, which was not modified from the energy reform, and therefore it is still taking the previous regulations (Energetic Reform, 2013).

A comparison between the electromechanical and digital meters identifies that the accuracy of the measurement in the digital meters has an error of  $\pm 0.5\%$  that can be attributed to different types of faults (faults to earth ground, overvoltage, magnetization) which are reflected in the consumption in kWh. In the case of electromechanical meters faults could pass imperceptibly due to measurement error.

An advantage of digital meters over electromechanical ones is the accuracy of the consumption signal frequency. If it is considered that the charge of the electric power measured in kWh corresponds to the registered peaks of greater current amplitude of the consumption spectrum by the supply voltage in low voltage. What places the digital meters as the most accurate relating to a fair charge for both parties (the user and the CFE).

The loss of the subsidy to the electric power service due to the extinction or replacement of the CFE and supply by foreign companies to the low voltage energy sector from the energy reform would represent a series of social and economic problems for the population, in addition to a danger for Mexico and the Mexicans in the next generations.

## Future works

A new project called Escalation of the measurement will be next in the list of pending projects that will continue in the modernization of the measurement. In this project it is planned to completely automate the connection and disconnection by satellite systems of the electricity supply based on its payment control, thus avoiding the taking of readings in a common way, increasing CFE's profit capacity, converting it into a competitive world class company.

This leads to a new unknown. What will happen to the workers in the measurement department? It is planned by the CFE that employees in this area will be relocated in other areas of the same, looking for this to be a more competitive globally with tendencies to overcome the competition that may originate the stay of foreign companies in the country according to the energy reform.

This will allow the CFE to keep the subsidies for the low voltage sector allowing thus improve the quality of life of Mexican families.

## Conclusions

The modernization of the low voltage measurement system in the Mexican territory was accompanied by advantages and disadvantages under an empirical comparison of the modern measurement system with respect to the one implemented in the country, causing a repercussion in the socioeconomic, cultural and service environment.

This led to problems such as the opposition of users to the change of the measurement system, which caused riots, myths and social movements, attributing the new measurement system to be implemented is not reliable in the measurement, which generated rumors in Mexicans.

For this reason some hypotheses of the modern systems of erroneous measurement were made as they are previously programmed to increase the energy consumption, however this new measurement system is previously tested by the equipment and materials testing laboratory (LAPEM) in which the measurement equipment passed through a calibration process ensuring its proper functioning in the laboratory and in the field, with the possibility of belonging to the prepaid or payment system at the cut-off date.

In the engineering analysis carried out it was found that the resistance to change is due to external factors that obey other interests and not precisely related to technological development. This total opposition puts the CFE in technological backwardness consequently to Mexico.

The CFE seeks with this modernization to be a more competitive company at a global level with tendencies to overcome the competition that may arise from the stay of foreign companies in the country according to the energy reform. This will allow the CFE to keep the subsidies for the low voltage sector allowing thus improve the quality of life of Mexican families.

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