JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Study of Types of Energy Meters and Metering – A Review

Monika Solanki[1], Dr. Priyamvada Chandel[2] , Dr. Anula Khare[3] , Deepa Warudkar[4]
[1] M. Tech. Scholar, Department of Electrical Engineering, Technocrats Institute of Technology Bhopal, Madhya Pradesh, India
[2,4]Engineering Officer , Energy Meter Test Laboratory, Central Power Research Institute, Bhopal, India.
[3] H.O.D , Electrical Engineering Department, Technocrats Institute of Technology Bhopal, Madhya Pradesh, India.
Corresponding Author : monikasolanki257@gmail.com

Abstract : This study effort compares fundamental forms of energy meter and metering with the objective of examining the different types of Energy Meters. The objective of this study effort is to guarantee that enough energy metering is employed for each given meter to deliver effective services to customers of electric powers. The types of energy meters and metering systems encapsulates a comprehensive analysis of the devices and methodologies used to record and bill electrical energy consumption. Traditional electromechanical meters, which utilize a rotating disk to gauge usage, are contrasted with modern digital and smart meters that afford real-time data and remote monitoring capabilities. The review delves into the operational principles, accuracy, and technological advancements in metering, highlighting the transition towards smart grids and IoT-enabled devices for enhanced energy management. It discusses the significance of accurate metering in energy conservation, billing efficiency, and grid reliability. The study aims to provide a holistic understanding of current metering practices and emerging trends in the energy sector. This study conducts a comparative analysis of fundamental energy meter types and their metering techniques, with the objective of exploring the diverse range of energy meters available..

Keywords: Electromechanical meter; Energy meter and Metering.

1. INTRODUCTION

An energy meter, also known as an electricity or electric meter, is an instrument that records the amount of electrical energy used by a household, business, or any device drawing power. These meters are essential for utility companies to bill customers, and they're calibrated in units of energy consumption, with the kilowatt-hour (kWh) being the standard unit. Readings are generally taken each billing cycle. To encourage energy conservation, demand meters are used to record the peak power usage over a specified period. Moreover, "time-of-day" metering changes rates based on the time, accounting for higher costs during peak hours and lower rates at off-peak times. In certain regions, these meters are equipped with relays to reduce the load during times of peak demand. Energy meters are installed in residential, industrial, and commercial settings to measure the electricity usage by various appliances and systems. Power is measured in watts, and consumption of one kilowatt over one hour equates to one unit of energy. These meters work by measuring the instantaneous voltage and current, computing the product to determine power, and then integrating this over time to calculate the total energy used. Depending on the nature of the electrical supply and the size of the load, meters can be single-phase or three-phase. For smaller, residential connections, meters can be connected directly to the circuit, whereas larger commercial setups require current transformers to manage higher current levels safely.

1.1 Basic Types of Energy Meters

Energy meters are categorized based on their functionality, technology, and application. Here are the basic types of energy meters:

Electromechanical Induction Meters: These are the traditional types that measure energy consumption using a rotating disk whose speed is proportional to the power usage.

Electronic Meters: These employ electronic components to measure the energy consumption and usually display the reading on an LCD screen. They are more accurate than electromechanical meters and can provide additional information like time-of-use.

Smart Meters: A subtype of electronic meters, smart meters offer real-time data and communication features that allow for remote readings, dynamic pricing, and better energy management.

Prepaid Meters: These require users to pay for electricity before consumption. The meter will disconnect the service once the paid amount is used up.

AMI (Advanced Metering Infrastructure) Meters: These are part of an integrated system that enables two-way communication between the meter and the utility company for better energy management and grid efficiency.

Sub-Meters: These are used to monitor energy usage for specific sections or equipment within a property, helping in detailed energy management and accountability.

Energy meters, also known as watt-hour meters, are categorized based on various criteria, which include:

The **display technology** used, such as analog or digital.

The **metering location**, which can be at the grid level, secondary transmission, primary, or local distribution points.

The **intended use case**, which varies from domestic to commercial and industrial settings.

Technical specifications, encompassing three-phase and single-phase meters, high and low type meters, and various accuracy classes.

Considering these factors, energy meters are broadly classified into three primary types:

Electromechanical/Induction Energy Meters, which measure energy through mechanical rotation.

Electronic Energy Meters, which use electronic components to measure and display energy consumption.

Smart Energy Meters/Prepaid Energy Meters, which are advanced meters incorporating features like real-time data, remote communication, and prepayment for services.

1.2 Electromechanical/Induction type Energy meter

The electromechanical or induction type energy meter is one of the oldest and until recently, the most commonly used device to measure electrical energy consumption. Here are some key points about this type of meter:

Working Principle: It operates on the principle of electromagnetic induction. The meter has a non-magnetic, metallic disc that is rotated by the flow of electricity through a coil. The speed at which this disc spins is proportional to the amount of electrical energy being used.

Construction: The essential components include a voltage coil which creates a magnetic flux proportional to the voltage, a current coil that produces a magnetic flux proportional to the current, and a rotating aluminum disc placed in the field of the voltage and current coils.

Calibration and Accuracy: These meters are calibrated in such a way that the disc completes a specific number of rotations for a unit of electricity consumed, typically kilowatt-hours. Over time, the accuracy can degrade due to wear and tear, especially in the bearings and the disc itself.

Advantages: Electromechanical meters are known for their simplicity, durability, and low cost. They do not require a power source to operate.

Disadvantages: They are susceptible to tampering and are less accurate than electronic meters. They also do not provide additional functionalities such as time-of-use metering or demand response, which are available with modern smart meters.

Applications: These meters have been extensively used in residential, commercial, and industrial settings for many decades. However, they are being increasingly replaced by electronic and smart meters due to the need for more detailed energy consumption data and grid management capabilities.

The traditional and widely recognized electromechanical watt-hour meter is known for its characteristic rotating aluminum disc situated on a spindle and flanked by two electromagnets. The disc's rotational speed is directly proportional to the electrical power being used, which is then tallied over time by a counting mechanism and gear assembly. This device is constructed with three electromagnets made of silicon steel laminations:

The series magnet has a coil with a small number of thick wire turns and is wired in series with the power line, carrying the current load.

The shunt magnet is wound with numerous turns of fine wire and is connected across the power supply, creating a magnetic flux in response to the voltage. The braking magnet, a fixed permanent magnet, exerts a reverse force to control the disc's rotation, bringing it to a stable equilibrium during normal operation and halting it when the power supply is interrupted.

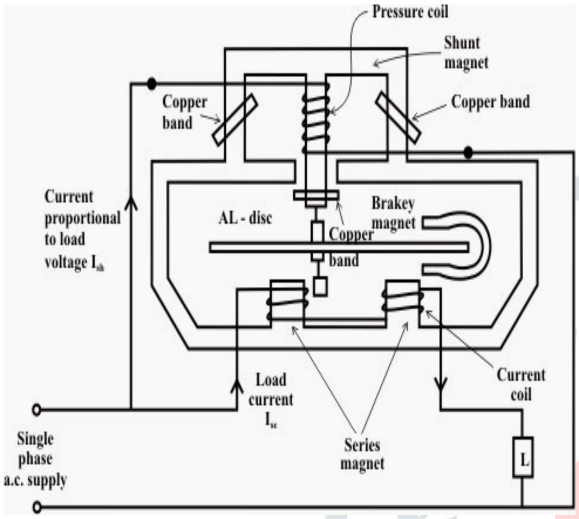

Figure 1. Internal Circuit of Electromechanical/Induction Type Energy Meter

The electromechanical induction energy meter functions by measuring the rotations of a conductive, non-magnetic metal disc, which rotates in proportion to the electrical power flowing through the meter, thereby indicating energy consumption. In a single-phase AC supply, this type of meter harnesses electromagnetic induction to count these rotations. The rotation count correlates directly with energy usage. While the voltage coil in the meter uses a minor, constant amount of power, which the meter does not record, the current coil uses power relative to the current's square, noted on the meter, particularly at higher loads. The disc is influenced by two induction coil sets that essentially form a linear induction motor with two phases [2]. These coils are arranged so that one responds to voltage and the other to current, with the voltage coil's magnetic field being phase-shifted by 90 degrees through calibration. This interaction generates eddy currents on the disc, producing a force that is in direct proportion to the instantaneous voltage, current, and their phase difference, or power factor. An opposing force from a permanent magnet, functioning as an eddy current brake, balances against this force and is proportional to the disc's rotational speed. The disc's steady rotation, reflecting the rate of energy consumption, turns a register that counts the rotations similar to a car's odometer, thereby tallying up the total energy usage. For different phase supplies, more coils are introduced to measure voltage and current appropriately.

1.3 Electronic Energy Meters

Electronic energy meters showcase energy consumption on Liquid Crystal Display (LCD) or Light Emitting Diode (LED) screens, with certain models equipped to send readings to remote locations. These meters are multifunctional, capable of recording various aspects of electricity consumption and supply, such as peak demand, voltage levels, power factor, and reactive power. They come in both analog and digital variants. Analog meters translate energy use into a corresponding frequency or pulse, which is then totaled using internal counters. For measuring voltage and current in each phase, analog meters employ a voltage divider and current transformers, respectively, which are connected directly to the load. Digital meters, on the other hand, utilize electronic components and processors to perform these measurements more accurately and provide additional functionalities. [3]

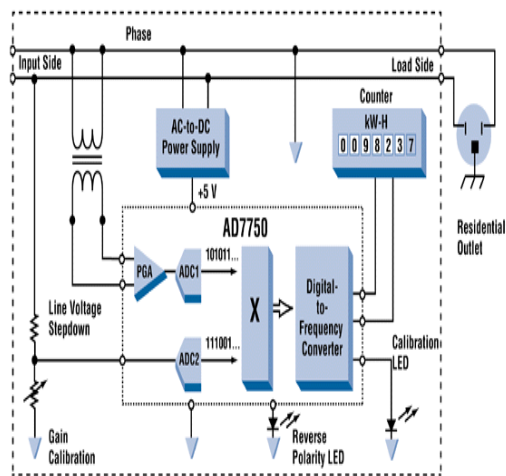

Figure 2 Internal Circuit of Analog Electronic Energy Meters

Digital energy meters represent an evolution from their analog predecessors, offering precision in measuring electrical parameters such as voltage, current, and power, with the readings prominently displayed on a Liquid Crystal Display (LCD). They are equipped with memory, typically an electrically erasable programmable read-only memory (EEPROM), capable of archiving consumption data for up to two years. Available for both single-phase and three-phase electrical systems, digital energy meters vary in functionality: single-phase meters generally track and display energy usage, while three-phase meters are more complex, providing tariff-based readings. This complexity is due to the varying energy rates during different times of the day; hence, these meters segregate the consumption into peak (T1) and off-peak (T2) periods to accurately reflect the cost of energy usage corresponding to these intervals. [3]

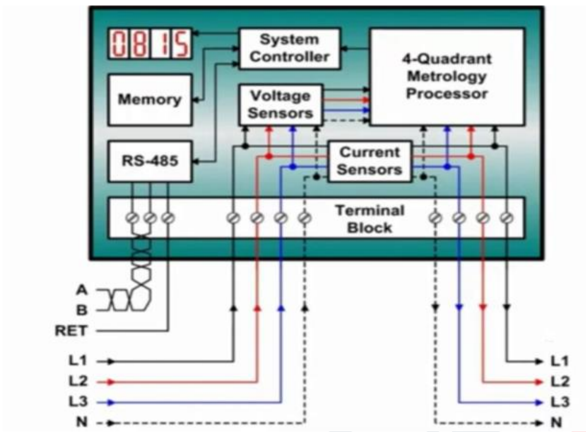

Figure 3 Internal Circuit of Digital Electronic Energy Meter.

1.4 Smart Energy meter

Smart energy meters are advanced devices that not only measure energy consumption but also have communication capabilities that allow for two-way data exchange between the meter and the utility provider. Here's a more detailed look at smart meters:

Digital Interface: Smart meters typically have a digital display that shows the amount of electricity used. The interface can also provide additional information, such as current power usage, peak demand, etc.

Communication Technology: They utilize wireless or wired communication systems to send the collected data to the utility company and receive instructions or updates. This can include Wi-Fi, cellular networks, power line communication, or radio frequency waves.

Real-Time Monitoring: Unlike traditional meters, smart meters can record usage in intervals as short as every 15 minutes. This allows consumers and utilities to monitor energy consumption patterns in real-time.

Remote Access and Control: Utilities can perform tasks like remote readings, connection, and disconnection without having to send a technician on-site. They can also update firmware or modify settings remotely.

Energy Management: By providing detailed usage data, smart meters enable more effective energy management. Users can adjust their consumption habits to reduce costs, especially during peak demand periods when energy prices are higher.

Support for Renewable Energy: Smart meters can handle the bi-directional energy flow, which is essential for homes with renewable energy sources like solar panels. They can measure the energy sent back to the grid as well as consumed.

- **Enhanced Security and Outage Response**: They can notify the utility company of power outages in real-time, speeding up the response time for repairs. Additionally, they often have features to detect tampering or abnormal usage patterns.
- **Challenges**: There are concerns about privacy and cybersecurity due to the amount of data transmitted. Also, the initial cost of installation can be high, and there might be resistance from consumers who are uncomfortable with the detailed tracking of their energy usage.

Advanced metering technology encompasses the use of intelligent meters that not only record energy usage but also process and relay that data back to consumers. These smart meters are capable of measuring electricity consumption, turning the power supply on or off remotely, and regulating the maximum amount of electricity that can be used. The system operates on Advanced Metering Infrastructure (AMI) technology, which enhances overall performance by providing real-time energy usage data and facilitating more dynamic interaction between utilities and customers.

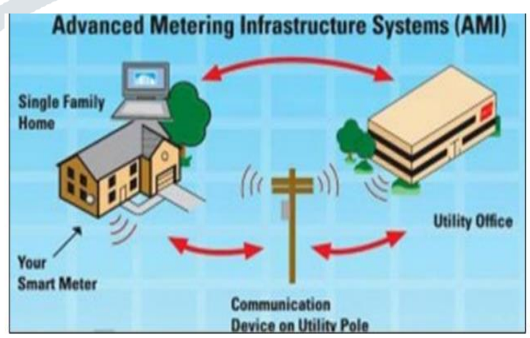

Figure 4 Advanced Metering Infrastructure (AMI) System Technology

Smart energy meters are highly capable devices that can send a wealth of data to utility companies, including energy consumption figures, various parameter readings, and alerts, while also being receptive to incoming information like automatic meter reading instructions, connection or disconnection commands, and software updates. These advanced meters minimize the necessity for physical meter reading visits for monthly billing. They incorporate modems that utilize diverse communication technologies such as telephone lines, wireless networks, fiber optic cables, or power line communications to facilitate this two-way data exchange [9]. A notable benefit of smart meters is their enhanced security features, which greatly reduce the potential for energy theft or tampering. Beyond merely tracking energy usage, these meters can transmit the data to utilities using communication channels like GSM/GPRS, radio frequency, or power line communication, allowing utilities to also remotely manage customer loads [10]. In addition to these primary functions, smart meters are instrumental in load management and in predicting future energy needs, aiding in the efficient operation of the power grid.

1.5 AMR Smart Energy meters

Automatic Meter Reading (AMR) smart energy meters are a type of smart meter specifically designed to automate the process of collecting data on energy consumption from energy meters and transferring that data to a central database for billing and/or analyzing. Here are some key features of AMR smart energy meters:

Automated Data Collection: AMR systems automatically collect consumption data from the meter and transfer it to the utility provider. This eliminates the need for manual meter readings.

Communication Methods: AMR meters can use various communication technologies such as radio frequency, power line carrier communication, or cellular networks to send data to the utility.

Frequent Data Transmission: These meters typically send data at predefined intervals, which can range from once a day to several times an hour, depending on the system's design and the utility's requirements.

Benefits: AMR technology reduces the costs associated with manual readings and increases the accuracy of billing by eliminating human errors. It also allows utilities to quickly detect and address issues such as leaks, outages, or tampering.

Limitations: While AMR meters can transmit data to the utility provider, they usually do not have two-way communication, meaning they cannot receive data or commands in return. This is a primary difference between AMR and the more advanced Advanced Metering Infrastructure (AMI) systems.

Customer Access: Some AMR systems provide a way for customers to access their usage data, often via an online portal, but they typically do not offer as much detail or as many features as AMI systems.

Easy Integration: For many utilities, AMR systems serve as a transitional technology that can be more easily and cost-effectively integrated into existing infrastructures compared to full AMI systems.

Automatic Meter Reading (AMR) refers to the technology used by energy meters to automatically record electricity consumption and transmit the data directly to the utility's server. AMR Energy Meters, a type of smart meter, are primarily focused on the one-way communication of usage data, lacking the capability for more interactive features such as load management or load forecasting, which are available in more advanced metering systems. They are designed for the singular task of sending energy usage information from the meter to the utility company's server without facilitating a two-way dialogue [4].

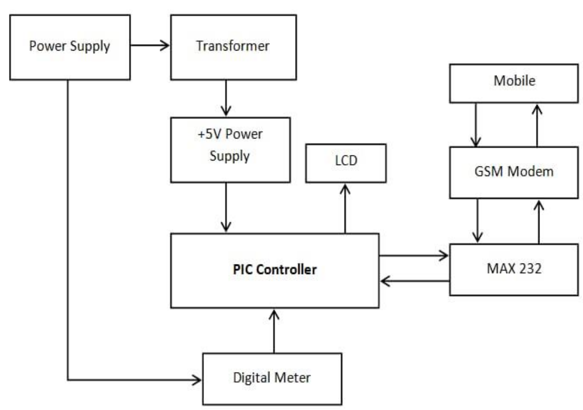

Figure 5 Block Diagram of AMR Smart Meter.

1.6 AMI Enabled Smart Energy meter

AMI-enabled smart energy meters are sophisticated devices that form an integral part of Advanced Metering Infrastructure systems, providing real-time, two-way communication between consumers and utility companies. These meters support a variety of functions beyond simple energy consumption recording, such as remote monitoring and control, dynamic pricing, and outage management. They can send detailed usage data to both consumers and utilities, enabling more efficient energy use, cost-saving through demand response programs, and improved grid reliability. Additionally, AMI meters facilitate the integration of renewable energy sources into the grid by managing energy flow from these distributed systems [12]. They play a crucial role in the evolution towards smarter, more responsive, and sustainable energy networks.

Advanced Metering Infrastructure (AMI) represents the cutting-edge in energy meter technology, offering a comprehensive solution for robust and efficient energy management. AMI systems facilitate bidirectional communication, allowing for data exchange from the utility server to the energy meter and back. This two-way communication capability enables utilities to remotely manage and potentially limit consumer energy usage directly from their offices. The integration of smart metering into the power grid involves the adoption of a variety of new technologies, software applications, and hardware components, tailored to the specific needs of electric power suppliers. With these smart meters, power companies are equipped with a sophisticated power infrastructure that combines information technology and communication capabilities to enhance electricity delivery to consumers. The dual-direction communication and energy flow give both suppliers and consumers the power to control, predict, and oversee electricity usage. While the integration of advanced IT and communication infrastructures continues to revolutionize the industry, it's noted that in some regions, utility companies still rely on decades-old systems. The growing demand for electricity and increased consumption present significant challenges to these utilities, leading to issues like power shortages, voltage instability, overloaded transformers, energy theft, and frequent load shedding [5].

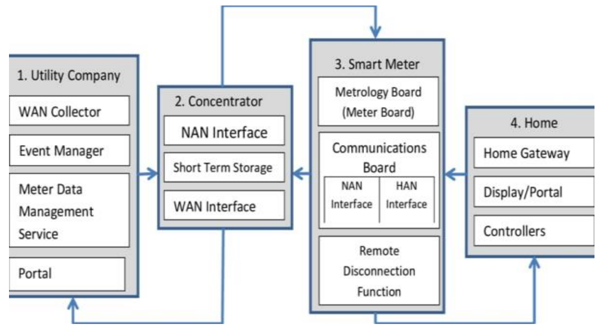

Figure 6 Block Diagram of AMI Smart Meter.

1.7 Smart Card Based Prepaid Energy Meters

Smart card-based prepaid energy meters are a pay-as-you-go solution for electricity consumption, where users pre-purchase credit and load it onto a smart card, which is then inserted into the meter to access the electricity supply. These meters are designed to help manage energy usage and expenditures more effectively by allowing consumers to pay in advance and track their consumption in real time. The use of smart cards also enables utilities to improve revenue management and reduce the instances of unpaid bills. Such systems are particularly beneficial in areas where billing collection is challenging and can also serve as a consumption-limiting mechanism to encourage energy conservation among users. The technology behind these meters often includes features like user-friendly interfaces, fraud prevention, and the ability to top up credits through various channels, making them a convenient option for both utilities and consumers [15].

Prepaid energy meters employing smart card technology consist of two primary components: the smart card itself, which is similar in appearance and material to a credit card, and the smart card reader. The smart card is embedded with a microprocessor (Central Processing Unit), a fixed Read-Only Memory, and an Electrically Erasable Programmable Read-Only Memory (EEPROM) that together run the smart card's operating system and manage its data. Consumers are required to preload their smart cards with a desired amount of credit units. These cards are then inserted into a reader that is integrated with the energy meter, forming a unified system. The reader records the available credit from the smart card, and as electricity is consumed, the meter deducts units accordingly. Once the balance depletes to zero, the system automatically cuts off the electricity supply until the card is recharged [6].

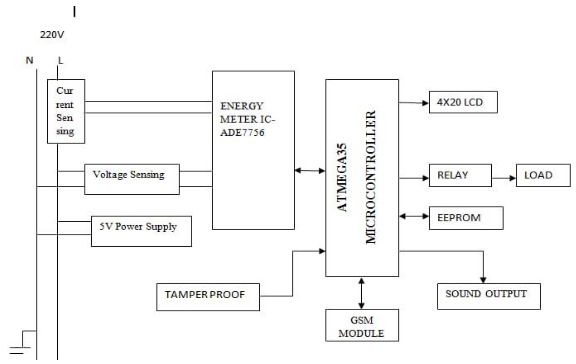

Figure 7 Block Diagram of Prepaid Smart Meter.

1.8 Energy meters metering

Electronic meters have advanced, employing various communication technologies like low-power radio, GSM, GPRS (General Packet Radio Service), Bluetooth, and RS485 wired connections. They now have the capability to store detailed usage data complete with time stamps, which can be transmitted instantly. The recorded demand alongside the usage profiles provides a precise depiction of a customer's power needs, which utilities use for both billing and infrastructure planning. Systems such as AMR (Automatic Meter Reading) and RMR (Remote Meter Reading) enable the collection of meter readings without dispatching personnel to the site. Electronic meters can send their data to a central billing location via telephone lines or radio signals. GSM modems attached to each meter and at the utility's central office facilitate automatic reading.

In energy metering, there are four recognized types:

Time of Day Metering (TOD): This system charges different rates for electricity based on the time of day, month, or year, encouraging customers to use less power during peak demand times. Rates are divided into segments like on-peak, off-peak, mid-peak, and critical peak, and customers are either incentivized or required to manage their usage accordingly.

Remote Metering: Originating in the 1960s, this method has evolved from remote pulse transmission to utilizing modern protocols and communication methods. Today's meters are based on sophisticated electronic technology and are often managed remotely.

Standards Metering: Collaboration between manufacturers and utilities led to early standardization in metering, with the ANSI C12 Code for electricity metering established in 1910 and the IEC metering standard from 1931. These standards set high accuracy benchmarks for meters, which remain relevant for residential use even today.

Power Export Metering : An increasing number of electricity consumers are setting up their own power generation systems for economic, reliability, or environmental reasons. When these customers produce more power than they consume, the excess can be fed back into the public power grid. To safely reintegrate this energy, customers must install specialized equipment and safety mechanisms to protect both the grid and their own systems from potential hazards like electrical faults or during maintenance operations. In some cases, excess power contribution is tracked by the customer's meter running in reverse when surplus energy is fed into the grid, effectively crediting the customer at the full retail electricity rate. Traditional meters without a ratchet mechanism can record the inflow and outflow of electricity, running backward during periods of net export.

The economic relationship between utilities and customers with regards to energy export is often regulated by law, where utilities may apply a margin between the price they sell electricity for and the rate credited to customers for their contributed power. Renewable energy sources, such as wind and solar, along with gas or steam turbines from cogeneration setups, are common origins of such surplus power. Another innovative concept is the use of plug-in hybrid electric vehicle batteries (vehicle-to-grid systems) as potential energy contributors. For these systems to work efficiently, a "smart grid" infrastructure is necessary, which employs advanced meters capable of detailed electricity tracking, remote management, and providing customers with time-based and price-based usage choices. Vehicle-to-grid solutions could be implemented in locations like workplace parking and public transit stops, allowing vehicle owners to charge at lower off-peak rates and sell excess power during peak demand times, thus receiving credits on their electricity bills.

Harmonics in Metering: Harmonics in the electrical supply are the distortions in the standard waveform of electric current, predominantly caused by nonlinear loads. Nonlinear loads draw power in an uneven manner, which contrasts with the smooth and consistent power draw of linear loads. Such loads include devices and equipment like switch-mode power supplies (SMPS), used in computers to convert

AC to regulated DC power, variable speed motors, office equipment like photocopiers and laser printers, and power backup systems like UPSs. While modern offices typically present single-phase nonlinear loads, industrial environments often introduce three-phase nonlinear loads, contributing significantly to the total non-linear load on electrical distribution systems.

The intermittent and intense current spikes from these nonlinear sources lead to a distorted current and voltage waveform, affecting the power quality. Power systems are designed to cope with some level of harmonics; however, when these constitute a large percentage of the load, various problems can ensue:

- Equipment such as cables, transformers, and generators can overheat and become scorched, potentially leading to fires.
- Harmonic resonance can create high voltages and circulating currents, causing further damage.
- Overheating can also afflict electrical distribution systems, leading to premature equipment failure and reduced lifespan.
- The false tripping of circuit breakers and unexpected generator shutdowns can occur.
- Voltage distortion can lead to malfunctioning of sensitive equipment.
- These harmonics can result in increased energy losses within connected devices and a lower power factor, which in turn can cause a rise in energy costs.

2. Conclusion

Upon reviewing the diverse range of energy meters and their operational mechanisms, we reach the conclusion that the choice of an energy meter is contingent upon its proficiency in facilitating effective power distribution and fostering a sound management infrastructure for the end-users as well as the electricity providers. Among the various meters scrutinized, the smart card-based prepaid meters, which are categorized under the umbrella of smart metering technologies, have emerged as the frontrunners. They distinguish themselves by offering exemplary service and an advanced information management system. These meters not only streamline service delivery but also enhance the interface through which consumers and power companies interact, thereby elevating the overall utility experience.

ACKNOWLEDGEMENT

The author would like to express her gratitude to the CPRI officials and Professor TIT Bhopal for extending their support and technical knowhow for submission of this manuscript.

References

[1] S. Dyer, " Survey of Instrumentation and Measurement.," *New York, USA: John Willey and Sons.*, 2001.

[2] J. F., " Menlo Park Reminiscences.," *Kessinger Publishing.*, 2010.

[3] B. Koay, S. Cheah, Y. Sng and Y. Tong, " Design and Implementation of a Blue Tooth Energy Meter.," *IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE).*, pp. 1474-1477., 2013.

[4] *M. M. Kwan B, "PIC based smart card prepayment system.," Student Conference on Research and Development., pp. 7803-7565., 2002.*

[5] *Depuru SS, Wang L, Devabhaktuni V, Gudi N. Smart meters for power grid Challenges, issues, advantages and status. In2011 IEEE/PES Power Systems Conference and Exposition 2011 Mar 20 (pp. 1-7). IEEE..*

[6] *Z. Ling , C. Sihong and G. Biao, "The Design of Prepayment Polyphase Smart Electriicity Meter System.," International Conference on Intelligent Computing and Integrated Systems (ICISS)., pp. 430-432., 2010.*

[7] L. Ning and L. Hong, " Design and Implementation of Remote Intelligent Management System for City Energy Resources Base on Wireless Network Study of Computer Application.," *International Journal of Engineering, Science and Technology.*, pp. 160 - 166, 2004.

[8] T. S. Harish M, "GSM Based Automatic Wireless Energy Meter Reading System .," *International Journal of Engineering Research.*, 2012.

[9] k. Reyan and k. Verne, " Google Plans Meter to Detail Home Energy Use.," *Retrieved December 17, 2019, from THE TECH CHRONICLES.*, 2009.

[10] C. F., " Cyber Security Issues for Advanced Metering Infrastructure.," *Power and Energy Society General.*, pp. 1-5. , 2008.

[11] K. A. Zaidi, H. Masroor and S. R. Ashraf, ,"Design and implementation of low cost electronic prepaid energy meter," *Multitopic*

conference, INMIC IEEE International,, 2008.

[12] Zheng J, Gao DW, Lin L. Smart meters in smart grid: An overview. In2013 IEEE green technologies conference (GreenTech) 2013 Apr 4 (pp. 57-64). IEEE.

[13] Preethi V, Harish G. Design and implementation of smart energy meter. In2016 International Conference on Inventive Computation Technologies (ICICT) 2016 Aug 26 (Vol. 1, pp. 1-5). IEEE..

[14] S. Kusui, N. Yamazaki and Y. Ikeda, "Electronic type polyphase electric energy meter.," U.S. Patent No. 4,217,545., 1980.

[15] R. caiceres and R. correand, "Study of active electric energy meters behavior of induction and electronic types.," *Transmission & Distribution Conference and Exposition: Latin America*, *TDC'06.*, 2006.