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Prepaid-Postpaid Energy Meter with Distorted Distribution Voltage to Prevent Electricity Theft

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***Abstract*—**Electricity theft is a comprehensive problem in both developing and developed countries. Although the theft causes great economic losses and reduces reliability of power grids, the problem continues to grow. This paper proposes a mathematical model of multi-featured prepaid-postpaid energy meter with distorted distribution voltage. The evidence shows that theft is increasing in most regions of the world. The financial impacts of theft are reduced income from the sale of electricity and the necessity to charge more to consumers. Electricity theft is closely related to governance indicators, with higher levels of theft in countries without effective accountability, political instability, low government effectiveness and high levels of corruption. Distorted distribution voltage is the most significant revision in the new configuration since traditional distribution voltage is directly consumable in electric powered devices and facilitates the theft. The proposed model is simulated and tested over MATLAB/ platform. The results obtained are promising and complying with the existing system.

Keywords:- Prepaid, Postpaid, Energy Meter, Distribution Voltage

I. INTRODUCTION

In any power system, losses of electricity, at transmission and distribution levels include technical losses and non-technical losses (NTLs) or commercial losses, both. Technical losses involve inevitable dissipation of electric energy into the equipment, losses in dielectrics, and conductors. Non-billed electricity and billed but unpaid electricity, either due to metering/ billing errors, or fraudulent behavior of consumers are the major reasons for NTLs. These NTLs enhance the costs to utilities, genuine consumers and states [1]. It is recorded that more than 20% of the electricity generated in India is lost due to rampant thefts [2]. Additionally, more than 30% of total electricity generated in India is lost due to thefts and inefficiencies in transmission and distribution [3].

These issues are quite often prevalent in Indian power distribution system. If these losses are minimized, a lot of electrical power can be saved, and thus the economy of the country will increase by increasing the revenue collection. This is partially possible using a smart energy meter. Because a smart energy meter enables the power utility company to gather electricity bills from the consumers before to its consumption except for postpaid customers. Therefore, the new smart energy meters are being placed in place of the conventional energy meters to improve the accuracy, towards the enhanced capability to control irregular billing and power theft [4]. These smart meters (SM) differ from traditional metering systems regarding their advanced communications and processing capabilities, enabling the collection of data regarding high resolution of consumption or consumer services (e.g. automatic efficient control of appliances, demand side management) [5]. The importance of introducing SMs, along with architectural model of a conventional energy meter and SM are explained in [6].

Also, the main differences between smart and conventional power meters, highlighting the new features, methodologies, possible functionalities and applications of modern SMs are discussed in [7]. A framework for characterizing and quantifying societal benefits, attributing to smart metering is presented in [8]. Moreover, nowadays, the energy consumption data collected from the advanced metering infrastructure implemented in smart grids identifies the possible defective smart meters and abnormal consumption patterns of consumers, to prevent the NTLs [9]. Besides, various SM data applications can add efficacy in demand side management, resulting in lower peak demand and operational costs, towards maintaining system security without any new investment costs in power system [10].

Power utility companies provide the facility to recharge the smart card or electricity bill payment from a remote place on customer's request at a suitable/ requested time. Pre-billing is bound to remove the unpaid bills and problems of human error during the billing meter, to ensure proper revenue for the power utility company.

II. TECHNICAL REVISIONS

The power losses occurred in power grids are divided into two groups: Technical and nontechnical losses. The technical losses are mechanical, electrostatic and electromagnetic losses occurring in the generation, transmission, distribution and conversion of energy in electric power grids. The nontechnical losses can be defined as illegal electricity consumption or electricity theft, which is made consciously by dishonest customers. The dishonest customers use several theft techniques such as illegal connection, misreading, power meter tampering and unpaid bills [3]. The following sections describe revisions required for existing power grids to solve the theft problem by considering known and probable electricity theft techniques. The revisions should be handled as a whole and zero tolerance policy must be applied against electricity theft.

Unusable Distribution Voltage

Distribution transformers step down high transmission voltage to low distribution voltage, which is directly consumable in electric powered devices. Therefore, utility customers can use utility electricity with a power meter and there is no need for an additional power converter. The power meters have no impact on utility power quality and they are only used to protect the cost benefits of utilities and their customers. Dishonest customers can use utility electricity by tampering or bypassing the power meter [7]. These theft techniques are easy particularly from overhead lines in rural areas since theft detections, which are made by utility staff, are impossible in every time. However, dishonest customers cannot use utility electricity without power meter in the case distribution voltage is harmful or insufficient for electric powered devices and it is safely used only with the power meter.

Using an external harmonic source in electric distribution centers is a practical and efficient way to distort the distribution voltage because of the following advantages. Firstly, the harmonics can be easily cleaned by a passive harmonic filter group, which is embedded in new power meters; hence, genuine customers are not adversely affected by distorted distribution voltage. Secondly, the distortion characteristic of the distribution voltage can be controlled by changing frequency and amplitude of the harmonic voltage. Therefore, different harmonic characteristics can be used for different customer types and regions. Thirdly, there is no need to change power architecture of existing distribution grids because only distribution transformers and power meters must be changed to implement the method. Finally, the harmonic voltage source needs no extra much power since harmonic voltage with low current is enough to distort the distribution voltage. These advantages reveal that use of an external harmonic voltage source is an easy and effective recyclable way for distribution voltage distortion.

Unusable Distribution Voltage for Street Lighting

Distribution voltage of street lighting systems has same electrical characteristics with usable home voltage, so overhead street lighting lines can also be used for electricity theft. In fact, there is no power in the street lighting lines at daylight hours owing to photocell sensors. However, dishonest customers deactivate the sensors to employ the lines for the theft, in which distribution voltage has low power quality because of overload. This theft technique also leads to street lights working during the whole day rather than only evening hours. Therefore, distribution voltage of street lighting system must be inconsumable for conventional electric powered devices to prevent this theft technique.

DC distribution voltage is more reliable and efficient for street lighting systems owing to improved led and power conversion technologies [8]. This is the reason why DC distribution voltage can be preferred to change traditional AC voltage of street lighting systems. Dishonest customers, who know DC voltage is insufficient for conventional electric devices, give up using street lighting lines to meet their electricity needs. DC distribution voltage of street light system can be used only with a DC/AC power converter by establishing an illegal connection. However, the use of a power converter is not a practical way to employ the lighting lines for the theft since the converters are expensive electronics equipment. Even so, this way must be considered as a risk for the theft and an effective precaution should be taken against it. Electricity consumption of street lights is generally stable and limited. If the lighting power characteristic is abnormally changed, there is a theft attempt. In these cases, the lighting energy must be automatically cut for a short time by power control center. After this short time period, if the characteristic abnormality of the lighting power continues, the time of energy cutting is gradually increased until utility staff interfere the lighting system.

III. CONFIGURATION MODEL

The working scheme of proposed model has been visibly clarified with the help of a block diagram shown in Fig. 1. This proposed model is a combination of three sub-models as follows

- Distribution Transform
- Energy Meter
- Power Utility

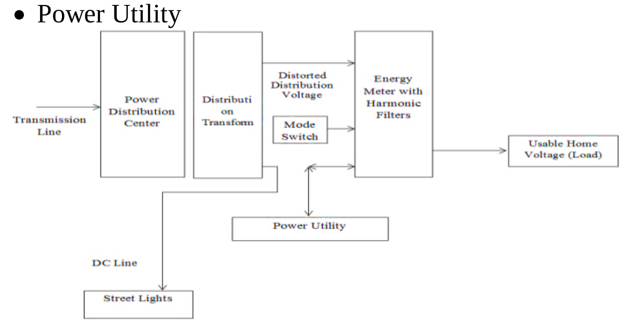

Figure 1: Block Diagram of Configuration Model

(i) Distribution Transform

The distribution voltage of the houses is distorted by an external harmonic source in the power distribution center. The power meter includes harmonic filters to eliminate harmonics of the distorted distribution voltage and provide reliable energy to domestic loads. 400 V DC voltage is utilized for the distribution voltage of street lights to make it unusable for traditional electric powered devices.

Figure 2 shows power components configuration of the power distribution center. Power distribution center includes a conventional transformer and power converters. The transformer steps down high transmission voltage to low distribution voltage to provide usable energy for residential areas. The AC/DC converter is utilized to produce 400 V DC, which is the suitable voltage level for DC distribution grids. The DC voltage is employed to supply street lights and the DC/AC inverter. The DC/AC inverter is serially connected to the distribution line of houses to distort its voltage characteristics with harmonics.

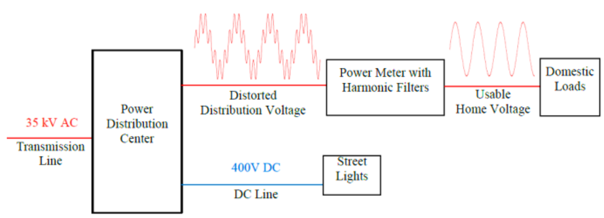

Figure 2: Use of distorted distribution voltage in an electric power grid

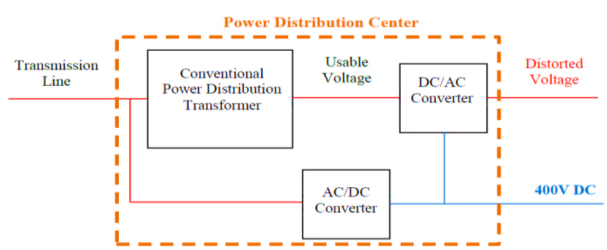

Figure 3: Power components configuration of the power distribution center

(ii) Energy Meter

This proposed energy meter basically operates in two modes, i.e., prepaid and postpaid modes [4]. For this purpose, here mode switch is utilized for choosing either prepaid or postpaid mode. Due to this feature, the consumer has the freedom to choose prepaid or postpaid mode as per their requirement. This energy meter consists of following components:

Sensors: In this proposed model, voltage and current sensors are utilized to quantify the voltage and current from the power supply.

Power Factor Model: MATLAB® simulated model of power factor block is presented in Fig. 2. It receives voltage and current from the power supply and calculates active, reactive and apparent power, and hence calculates the power factor to be transferred to the smart card.

Latching Relay: A latching relay is an interconnecting link between the consumer's load and power utility supply. The opening and shutting off this relay depend on the balance or time present in the smart card [15]. In the event of prepaid mode, if the smart card has sufficient balance, it remains shut and keeps the power supply continuous to the consumer's load. When the smart card runs out of balance, it opens and detaches the load from the supply. At the point when the smart card has insufficient time, it operates and detaches the load from the supply. Consequently, notwithstanding when the energy meter gets the voltage supply, it does not reach the consumer's load as the latching relay remains open due to the absence of balance or time in the smart card. Since the latching relay also consumes some amount of electrical energy, it has been included in the computations made by the meter and smart card.

DC Power Supply: The DC power supply unit gives the operational voltage of 5volts for the Microcontroller unit, Buzzer and LCD display etc. Circuit diagram of DC power supply is shown in Fig. 4.

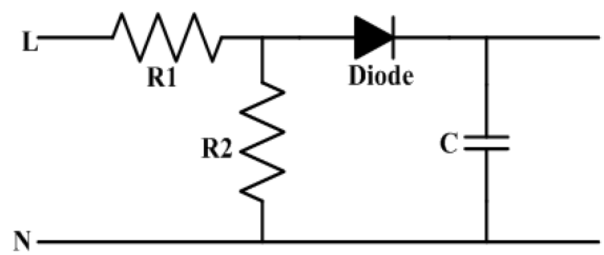

Figure 4: DC Power supply

(iii) Power Utility Company

This proposed energy meter transfers the data to the power utility company through wireless communication at stored by power utility company at each instant. Utility company always monitors the energy meter remotely.

IV. SIMULATION RESULT

An AC/DC converter is utilized to produce 400 V DC voltage that is needed for harmonic production and street light power distribution. A DC/AC power converter is employed as a harmonic supply, whose output is serially connected to the distribution line to distort the distribution voltage with the harmonics. The distribution grid has a formal costumer and a street light that are supplied from unusual distribution voltage. The power meter of the costumer has passive harmonic filters, which are compatible with produced harmonics in the power distribution center. Therefore, the distorted distribution voltage has no adverse effects on the costumer's loads since the filters eliminate the harmonics.

Relationships (1) - (5) show mathematical modeling of energy metering and measurement of the related parameters.

$$S = V_{rms} \times I_{rms}$$

$$\cos\theta = \frac{P}{S}$$

$$E = P_{avg} \times t$$

$$R_b = \frac{R_a}{T_R}$$

$$T_r = \frac{R_b}{P_{avg}} - t$$

Where, S = Apparent power
P = Active power demand
$\cos\Theta$ = Load power factor
P_{avg} = Average active power demand
E = Energy consumption in time t
R_b = Total recharged balance
T_r = Reaming time for next recharge R_a = Recharged amount and
T_R = Tariff rate

The average of the active power is net energy transmitted but the average of reactive power is zero, i.e., no net energy is transmitted. Thus, it clear that the reactive power keeps oscillating from the source to load and vice versa. It is also known as imaginary power. Therefore, residential consumer only pays for active power; whereas, utility company applies charges for reactive power (in form of penalty over poor power factor) for commercial consumers.
Consumer's loads of various values of resistances from 90 Ω to 1500 Ω are associated with the proposed energy meter. Readings and estimations are tabulated in Table 1.

Table 1: Measurements under Varying Resistance

Resistance (Ω)	V_{in} (V)	I (A)	p.f.	Load (W)	Energy (Wh)
1500	220	0.147	1	32.27	645.3
1400	220	0.16	1	34.57	691.4
1300	220	0.17	1	37.23	744.6
1200	220	0.18	1	40.33	806.7
1100	220	0.20	1	44.00	880.0
1000	220	0.22	1	48.40	968.0
900	220	0.24	1	53.78	1076.0
800	220	0.28	1	60.50	1210.0
700	220	0.31	1	69.14	1383.0
600	220	0.37	1	80.67	1613.0
500	220	0.44	1	96.80	1936.0
400	220	0.55	1	121.00	2420.0
300	220	0.73	1	161.30	3227.0
200	220	1.10	1	242.00	4840.0
100	220	2.20	1	484.00	9680.0
90	220	0	1	0	0

Table 2 shows the energy consumption pattern under a time-varying condition in prepaid mode, when the consumed load is 537.8 W. From this table, it can be observed that as the energy consumption increases, remaining balance and remaining time decreases linearly with respect to time.

Table 2: Energy Consumption under Time-Varying Condition

Time (hour)	Energy (Wh)	Balance (KWh)	Remaining Time (M:D:H:m)
0	0	10.000	0:0:18:36
1	537.8	9.462	0:0:17:36
2	1076.0	8.924	0:0:16:36
3	1613.0	8.387	0:0:15:36
4	2151.0	7.849	0:0:14:36
5	2689.0	7.311	0:0:13:36
6	3227.0	6.773	0:0:12:36
7	3764.0	6.236	0:0:11:36
8	4302.0	5.698	0:0:10:36
9	4840.0	5.160	0:0:9:36
10	5378.0	4.622	0:0:8:36
11	5916.0	4.084	0:0:7:36
12	6453.0	3.547	0:0:6:36
13	6991.0	3.009	0:0:5:36
14	7529.0	2.471	0:0:4:36
15	8067.0	1.938	0:0:3:36
16	8604.0	1.396	0:0:2:36
17	9142.0	0.8578	0:0:1:36
18	9680.0	0.3201	0:0:0:36
19	0	0	0:0:0:0

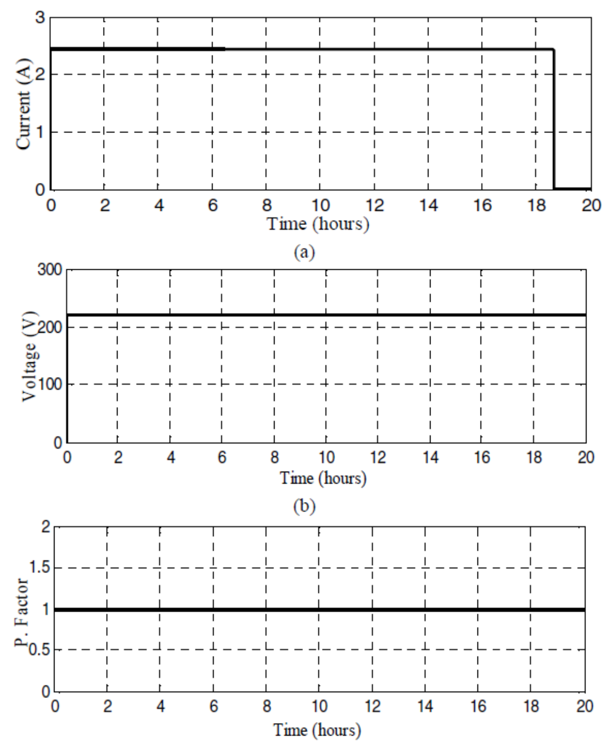

Figure 5: Measurement of various parameters, (a) Output current, (b) Input voltage, and (c) Measured power factor

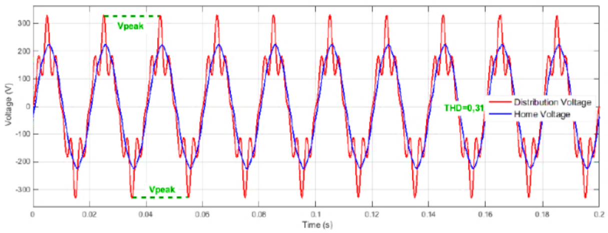

Figure 6: The characteristic of distorted distribution voltage

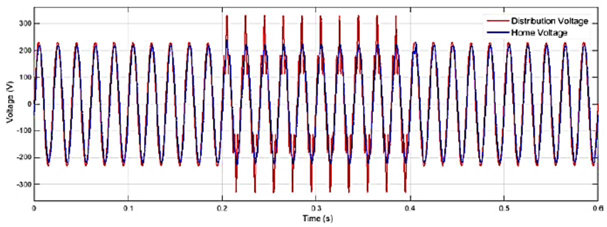

Figure 7: Intermittent harmonic distortion in electric distribution voltage

V. CONCLUSION

This paper displays a model of prepaid/ postpaid energy meter with technical revisions required to prevent electricity theft and presents a new electric distribution grid model including the revisions. This is an effort towards enhancing the revenue collection for the scheduled supply and revisions are determined by considering widely used electricity theft technics and included appropriate technological solutions against the theft technics. In the new model, inconsumable distribution voltage has a key role since consumable distribution voltage facilitates the theft and better efficiency in the measurement of rated load, power factor, output voltage, output current and system behavior. It is efficient for monitoring and controlling of energy consumption.

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