Comparison between Power Line Carrier Communication Based Metering, GSM Based Metering & Keypad-Operated Pre-paid Metering in Kenya

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Abstract – Real time energy monitoring by power utilities is an important energy management practice that is becoming a norm in developing countries. The importance is highlighted by the challenges that follow with improper or no energy monitoring. Examples are revenue losses incurred by utility companies due to vandalism, energy wastage and high electricity bills incurred by electricity consumers. Due to these reasons, utility companies and electricity consumers are employing various energy monitoring techniques. Kenya Power, a power distribution company in Kenya, is currently installing Global System for Mobile Communication (GSM) based smart meters as a pilot program with the aim of energy monitoring. They have also installed Keypad Operated Pre-paid meters to reduce the losses they incur due to vandalism.

In this paper, a low voltage Power Line Communication (PLC) metering system is proposed. Its efficacy as a viable energy monitoring platform is compared to both the Keypad Operated Prepaid and Global System for Mobile metering systems employed by Kenya Power. In particular, gaps in the established systems are highlighted and their impact presented. This is done through a cost analysis, efficiency analysis and reliability analysis comparison of the three metering techniques. The proposed system is then observed to address these gaps in a significant manner.

Keywords - Energy Metering, Energy Monitoring, Global Service for Mobile Communication (GSM), Keypad Operated Pre-paid metering (KOP), Low Voltage (LV), Power Line Communication (PLC).

I. INTRODUCTION

As Kenya aims on achieving Vision 2030, there has been a significant increase in the number of connected electricity consumers to the grid. Electricity connection rates stand at 23% in Kenya, the highest percentage connection rate in East Africa.

A. Statement of the Problem

Kenya has an average power transmission and distribution loss rate of 16.9%. These are the losses in transmission between sources of supply and points of distribution and in the distribution to customers.

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Fig 1 illustrates the increase in number of connected customers which can be attributed to the Government's aim to have full connectivity by 2020.

With an increase in connected customers, the system stands a high chance of power loss. The world's average power transmission and distribution loss rate stands at 8.1%. This shows that Kenya is above the world's average power transmission and distribution loss rate.

Power losses are a result of weak transmission and distribution network. Kenya Power losses stood at 18.1% in 2014 compared to 18.6% in 2013. It is estimated that 1% of power loss is equal to 1 billion shillings lost revenue. From Fig 1, the increase in power loss in the year 2011 can be attributed to the increase in connected customers. 8% of these power losses can be directly attributed to illegal connections and theft. This is a 3.3% increase in total power losses from 2011 to 2016. This loss is estimated to be 8 billion shillings annually. Fig 2 illustrates the trend in percentage power losses in selected African countries.



Fig 1: % Power Losses in Selected African Countries.

Blackouts are a major problem facing the country currently. Kenya Power is therefore deemed an unreliable service

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provider. Reporting the outages is tedious and the utility company takes a long time working to restore power back to its consumers. It is a problem especially if the fault occurs at distribution level. This is so as it takes a long time to troubleshoot. It is estimated that industries on average lose 5% of the monthly electricity bill in certain sectors and as high as 18% in other sectors. The industries switch to generators when the outages occur increasing their cost of production, hence the continued high prices of commodities. Kenya Power also suffers huge revenue losses during blackouts.

The current distribution network has had no major upgrades since it was first constructed. The network is also outweighed by the rapid electrification the government has embarked on. Having served only 2.2 million households since it was built, the line is now expected to serve 5.5 million households which is about 60% of the country's population.

The network is also expected to distribute an additional 657 MW that has been generated since 2013 as the government targets to hit the 5,000MW power generation goal.

B. Existing Solutions to the Problems

Kenya Power has recently embarked on several projects in a bid solve to the above mentioned challenges. Some include;

- Replacing Electromechanical and Electronic Post-paid meters with Key-pad Operated Pre-paid prepaid meters. Currently there are 160,000 prepaid users in Nairobi North area out of 450,000 Kenya Power customers in the area.
- Network refurbishment and expansion. The Company spent about 11 billion shillings in 2014 on network refurbishment and expansion, which included automation and upgrade of the system, undergrounding of cables, replacement of wooden poles with concrete ones, and creating adequate redundancy in the system. System losses as a percentage of energy purchased have therefore reduced to 18.1% in 2014 from 18.6% in 2013. A 0.5% reduction translating to a 500 million shillings contribution to profits. With the investment in system upgrade, a continued reduction in system losses is expected.
- Installation of GSM Based smart meters to large power consumers. The Company has spent 3.2 billion shillings to connect 4,426 large power consumers, out of 5,600 in the country.

II. BACKGROUND INFORMATION

A. Keypad – Operated Pre-paid Meters

These are electronic pre-paid energy meters with keypad systems for inputting the credit. The security of keypad payment system is very low. The main reason is that the algorithm that generates the key is stored inside the meter and can easily be hacked.

Key-pad pre-paid energy meters are getting obsolete but

they may still be cost-effective for remote areas, where twoway vending may not be feasible. These are the kind of pre paid meters that are currently being installed by Kenya Power.



Fig 2: Block Diagram of a Pre - Paid Electronic Meter.



Fig 3: A Pre – Paid Electronic Meter.

B. GSM – Based Smart Meters

GSM Based smart meters digitally send meter readings to the utility company via a GSM network. This ensures more accurate energy bills. These meters also enable monitoring so consumers can better understand their consumption. Kenya Power is installing GSM – Based smart meters for large power consumers as a pilot program. The system is facing challenges as some meters are not able to send data because there is no network coverage. The meters are also bulky, expensive and costly to install.



Fig 4: Block Diagram of a GSM – Based post – paid smart meter.



Fig 5: GSM - Based post - paid smart meters being installed.

III. POWER LINE COMMUNICATION BASED SMART METERS

A Power Line Communication System is a system whereby communication signals are sent and received from the household to the utility company through a 50Hz currentbearing power line. The concept of PLC is quite old but not brought into use on large scale for commercial purpose. There are several reasons why the technology has not been adopted as the current communication technique, and the main ones are noise, multipath and signal attenuation.

In order to achieve power line communication over low voltage lines (240V), a couple of features need to be taken into consideration - a power line communication modem, a coupling circuit to interface the PLC modem to the power line, source data and message frames, modulation techniques, medium access control (MAC) layers, attenuation and signal to noise ratio.

DESIGN CONSIDERATIONS

Power Line Communication Modem

Fig 7 describes a power line modem hardware design. Data to be transmitted is modulated onto a high frequency then passed through a coupling circuit for transmission. The received data goes through a coupling circuit where power with low frequency is first filtered out by a low pass filter and the high frequency signal carrying data is then filtered out using a high pass filter. The high frequency signal is demodulated back from the modulated carrier.

Power Line Modem Integrated Circuits

The use of power line modem integrated circuits simplifies the PLC modem circuit. The modulator, demodulator circuits and interfaces to the microcontroller are now all embedded in single IC. The microcontroller may write data bytes to the communication port of the modem IC using a level converter.

With the use of a power line modem IC, a level converter IC, a power supply circuit, an analog front end, a coupling circuit and an external oscillator circuit are required to design in a power line modem device.



Fig 6: Block Diagram of a Power Line Communication Modem

Coupling Circuit

The function of a coupling circuit in a power line modem is to create an efficient high-pass filter to remove the 240V AC, 50Hz signal of the mains, without attenuating the incoming high frequency signal. A coupling circuit should be designed to match the modem communication system and power distribution system.



Fig 7: Block Diagram of a Power Line Communication IC

Source Data and Message Frames

For accurate information to be sent, addresses are given for the PLC meters. When the PLC meter communicates with the receiving device, it will put its address in the address field. Fig 9 below shows an example of a message frame which consists of four fields, preamble, identifying address, data field, and stop bit. The data field in this case will be the meter reading coded in binary form. The message frame will always start with preamble to signify the device that a message is coming and always ends with a stop bit.

PREAMBLE	ADDRESS	DATA	STOP BIT
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Fig 8: Figure showing an example of a message frame.

Modulation and Demodulation Techniques

The accuracy of the data coming from the transmitter and receiver is determined by the efficiency of the modulation or demodulation process. The modulation band selected for power line communications must meet the required data rate and must maximize resistance to various noise interferences occurred in Power Lines.

Communicating at the power line communication robust modulation techniques like Frequency Shift Keying (FSK), Code-Division Multiple Access (CDMA) and Orthogonal Frequency Division Multiplexing (OFDM) are demanded.

For low cost, low data rate applications, such as power line protection and tele-metering, FSK is seen as a good solution. For data rates up to 1Mbps, the CDMA technique may provide an effective solution. However, for high data applications beyond that, OFDM is the technology of choice for PLC.

Medium Access Control (MAC) Layers

The MAC protocol specifies a resource sharing strategy i.e. the access of multiple users to the network transmission capacity based on a fixed resource sharing protocol. There are various protocols for MAC Layers in power line modems and they are: Polling, Aloha, Token passing schemes and Carrier Sense Multiple Access (CSMA)

Signal Attenuation and Signal to Noise Ratio

Signal Attenuation

Signal attenuation due to network loading ranges from 40 to 100dB per kilometer. The actual level signal attenuation is the number of loads connected to the main line which determine the main parameter. In power line channel, received signal power can be modelled as a function between transmitter and receiver with a specified distance.

Signal to Noise Ratio

Signal-to-noise ratio (SNR) is a key parameter when determine the efficiency or measure the performance in the communications system. The signal-to-noise ratio (SNR) is given as;

$$\frac{S}{N} = 20 \log_{10} \left(\frac{V_s}{V_n} \right)$$

Where;

 V_s is the mean voltage level of the signal.

 V_n is the mean voltage level of the noise.

The result obtained on this parameter is related to the efficiency of a communication system. The higher the SNR, the better is the communication. Select appropriate power communication module with this capability of improving the signal to noise ratio module is essential for each PLC meter.

DESIGNED METER

Based on the above mentioned design considerations, a power line communication smart meter was designed. Fig 10 and 11 show the block diagram and simulation of the designed power line communication based real time energy meter.



Fig 9: Block Diagram of the Designed PLC Energy Meter.



Fig 10: Simulation of the Designed PLC Energy Meter in Proteus Software

IV. FINDINGS AND DISCUSSIONS

The following is a comparison of the key findings that were identified by the researcher;

TABLE I COMPARISON OF THE METERING TECHNIQUES

Kev-nad Onerated	GSM Based	PLC Based Metering
ney pud operated	Obiii Dubeu	I DO Dasea metering
Pro-paid Mataring	Motoring	
i i c-paiù Metering	Metering	

1.	It is accurate.	1.	Real time	1.	It is cheap.
2.	The tedious		energy	2.	Easy detection
	task of		monitoring.		of power
	paying the				outages.
	bill and	2.	Easy	3.	Data from
	the bill is		detection of		remote areas is
	eliminated		power		accessible.
3.	Consumer		outages.	4	Real time
	awareness.		0		energy
4.	Prone to	3.	Brings an		monitoring
	vandalism.		end to	5	Droodbond DLC
5.	It cost Ksh		estimated	5.	
	13 billion		billing.		may become a
	to connect	4.	Hazardous		reality.
	500,000		radiation	6.	Smart home
	customers.	5.	Bulky, and		applications.
			unreliable.	7.	Prone to noise.
		6.	High	8.	It would cost
			installation		Ksh 11 billion
		7	COSL.		to connect to
		/.	3.2 hillion		500,000
			to connect		based on the
			4.426 large		cost of
			power		developing the
			consumers.		prototype.

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V. CONCLUSION

Kenya's average power transmission and distribution loss rate of 16.9% is above the world's average that stands at 8.1%. It is evident that there is a need for real time energy monitoring in the current systems. The Proposed system addresses these problems at a lower cost compared to other metering techniques. Low-cost broadband may become a reality in areas that cannot get cable or wireless broadband and broadband internet access from every socket in every room will be possible when using power line communication. Adopting the system will also create opportunities in load forecasting, load scheduling and load shaving from the real time data obtained from the meters.

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