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**Research Article**

# Automatic Meter Reading using Power Line Signaling and Voltage Zero-crossing Detection

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**Abstract:** In India, the electric power transmission and distribution loss is very high, about 7% in transmission and 26% in distribution. Though deployment of automated meter reading system will reduce losses, particularly in distribution, penetration of automated meter reading is low due to high costs involved. World over, the Two-Way Automatic Communications System (TWACS) is the most widely used power line communications technology offering two-way communication between substation and end users. The TWACS introduces disturbance on the power system voltage for short durations near zero-crossing to generate the outbound (from substation to end user) signal. To generate the inbound (from end user to substation) signal, short duration current pulses are introduced, near voltage zero-crossings. Information is generated as a sequential combination of voltage disturbances for the outbound signal and current pulses for the inbound signal. The current study proposes a low-cost modification of the TWACS to reduce voltage and current harmonics. The proposed system has been modelled and simulated using SIMULINK/SIMPOWER Systems. The simulation results show that there is a reduction in voltage harmonics from 0.84 to 0.17% and in current harmonics from 2.07 to 1.10%.

**Keywords:** Harmonics, power line communication, power line quality, smart grid, smart meters

## INTRODUCTION

Automated Meter Reading (AMR) refers to an energy meter reading system that makes it possible to read electronic energy meters remotely. It is generally agreed that any system that enables meters to be read at a distance of 100 m or greater from the meter position) is true AMR (Allan, 2006). AMR solutions were primarily developed to overcome the problems of manual reading, today, it has become a necessity for effective energy management and accounting (Khalifa *et al*., 2011). The effectiveness of AMR to detect and discourage theft and other ways of unmetered consumption is enormous, based on the experience of developing countries (Pedro, 2009; Cavdar, 2004; Ghajar and Khalife, 2003).

Due to the emphasis on energy management, AMR technology has shown remarkable changes over the years. In 1970s, power line carrier and fixed-line telephone-based AMR technologies began to evolve. The two major product developments were EMETCON and TWACS. However, the fixed-line telephone-based products never made a big impact with the electric utility since interfacing the electric meter with the telephone line was a proving to be a hurdle. In 1980s, the focus of the AMR industry turned to drive-by radio systems. The early 1990s saw the development of fixed radio-based networks where the radio receivers, transmitters and related infrastructure are installed in the field. Another big development in the mid-1990s was the Turtle system that earned its name because it was extremely slow. Over the last 20 years, as technology evolved, the utilities have embarked on large-scale implementations of AMR and these implementations have evolved into what is now called Advanced Metering Infrastructure (AMI). The technology continues to evolve (from one way AMR, two way AMR, AMI, to Smart Grid AMI) as is seen with the current rolling-out of Smart Grid technology (Hawkins, 2010). Smart grids are extensions of AMI systems, which are themselves built upon AMR systems (Ipakchi and Albuyeh, 2009).

Power Line Communications (PLC) based AMR system is the utility company's preferred technology since a dedicated communication infrastructure only for metering is expensive and hence using an existing network is a more cost effective solution. The advantages of PLC technology include leveraging the use of existing utility infrastructure, improved cost effectiveness for rural lines and in challenging-terrains and the capability to work over long distances. Though Radio Frequency (RF) based communications are cost-effective for suburban areas (Robert, 2012), there are concerns on human exposure to RF sources when RF based systems are used. In its report, Health Impacts of Radio Frequency Exposure from Smart Meters, the California Council on Science and Technology provides the guide lines on exposure limits. Further, compared

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with RF based systems, the PLC technology offers inherent data security since access to transformer stations is highly protected and supervised, power cables are typically laid under-ground and carrying signals on power lines inherently provides a form of natural protection due to higher voltage levels.

The three popular systems that offer AMR solutions via power line communications are.

**Turtle system:** Turtle System-2 (TS2) is a two-way AMR system that allows command and control of end user energy meter. It allows simultaneous transmission of commands from utilities to end users and meter readings from end users to utilities. However, this system is extremely slow. The data packet from each meter is 63 bits and each packet is read once every 22 h, resulting in a bandwidth of about $8\times10^{-4}$ bps (Galli *et al*., 2011).

**EMETCON system:** In EMETCON (Electronic Metering and Control) system, the data packet used for AMR is 52 bits and the time taken for a reading is 3 to 6 sec, resulting in a data rate of approximately 17 bps. EMETCON AMR can be installed with fixed network architecture, or can be used as portable system for hard-to-read meters and tough-terrain routes. Hence this system is popular in mountainous and rural areas.

**TWACS:** The TWACS is the largest PLC based AMR deployment with more than two million end users. It is a fixed network communication system that uses patented technology. The TWACS is unique among PLC solutions in that it does not generate high frequency voltage waveform which is coupled to the power line (David and Michael, 2011). This system works by introducing disturbances in the voltage waveform near the voltage zero-crossing point for outbound signal and by introducing current pulses near voltage zero-crossing point for inbound signal. This method of generating signals is also known as Power Electronics Signaling Technology and this signaling method is also used to facilitate HVDC transmission schemes and FACTS systems (Wilson and Wencong, 2010). The TWACS has been demonstrated to have a long range and to be robust against harmonic noise (Mak and Maginnis, 1995). The data packet used for AMR is 8 to 15 bytes long. A two-way transaction for every meter takes about 8.8 sec, with about half the duration for outbound data packet and the remaining time for inbound data packet. Further, all the three phases can be communicating simultaneously, adding to parallelism. This system works by transmitting data at about 30 bps on a single line and with parallelism the transmission rate is about 90 bps (Anatory *et al*., 2013). The transmission rate of TWACS is the highest amongst the three systems compared in this study.

In this research study, a modification to TWACS is implemented to minimize harmonics by counting voltage zero-crossings between two successive voltage disturbances to generate outbound information and between two successive current pulses to generate inbound information.

## METHODOLOGY

**TWACS outbound signal generation:** The TWACS is a binary coded communication system that uses the system voltage as carrier. Hence it is not required to take into account carrier attenuation. Further, the technique of creating the outbound signal is simple. As shown is Fig. 1a, a thyristor is shunt connected across the secondary of the distribution transformer. The thyristor is switched ON about 5° ahead of the voltage zero-crossing point and conducts for a short duration. During the conduction of the thyristor which is a controlled short circuit, a small voltage sag as shown in Fig. 1b, is created near the zero-crossing point. The existence of this sag represents a signal. As it is a voltage disturbance, the sag is seen by all the end user energy meters downstream. As shown in Fig. 2, the signal is extracted using a bipolar threshold detector-in the presence of the signal the voltage is within the threshold for $(\Delta T+\delta)$ duration and in the absence of the signal the voltage is within the threshold for $\Delta T$ duration.The duration when the voltage is within the threshold is measured at each negative-going zero-crossing and two such consecutive durations are compared and $(\Delta T+\delta)-\Delta T=\delta$ signals the presence of bit "1" and $\Delta T-(\Delta T+\delta)=-\delta$ signals the presence of bit "0".

The voltage waveform required to generate the bit pattern "10110" is shown in Fig. 3. At 50-Hz frequency, the bit rate is 5 bits every 200 msec, or 25 bps. There are five voltage disturbances in the 10-cycle interval, with each voltage disturbance distorting the sinusoidal waveform, leading to generation of voltage harmonics.

**Proposed method for outbound signal generation:** To reduce the voltage harmonics, the proposed method uses the count of zero-crossings between two voltage disturbances to generate information. For example, to generate 22 (decimal equivalent of the bit pattern "10110"), the technique shown in Fig. 4 is used.

This requires 22 half-cycles, or 11 full-cycles. At 50-Hz frequency, the bit rate is 5 bits in 220 msec, or 22.7 bps. There are only two voltage disturbances compared to five voltage disturbances created in the TWACS.

In the proposed method, the bit rate depends on the information to be transmitted-larger the decimal value, lesser the bit rate. For example, to transmit a decimal value of 100, one hundred half-cycles, or 50 full-cycles are required. This is equivalent to transmitting the bit pattern "1100100" (binary equivalent of decimal 100) in 50 full-cycles, resulting in a bit rate of 7 bps. Though this is smaller than the bit rate of 25 bps (at 50-Hz

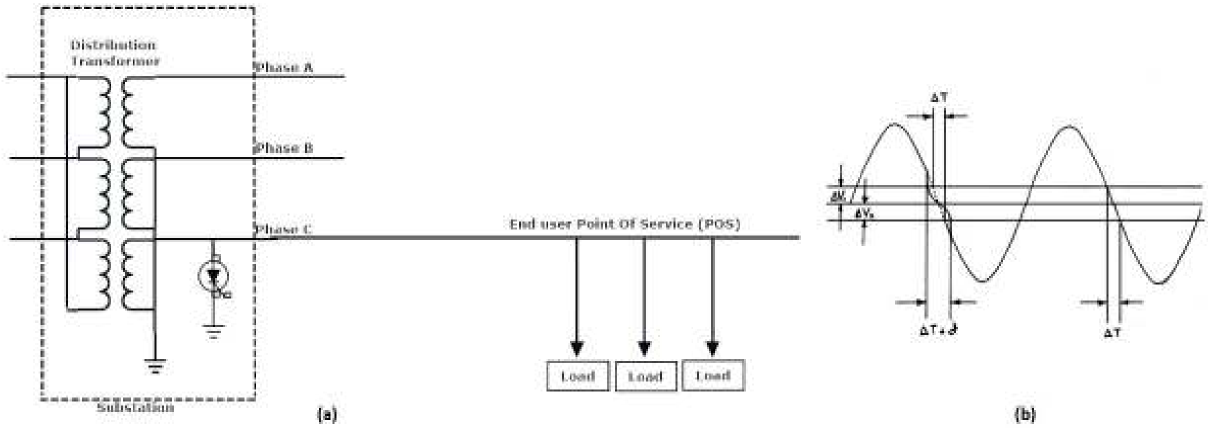



Fig. 1: TWACS outbound signal generation, (a) schematic diagram, (b) voltage waveform

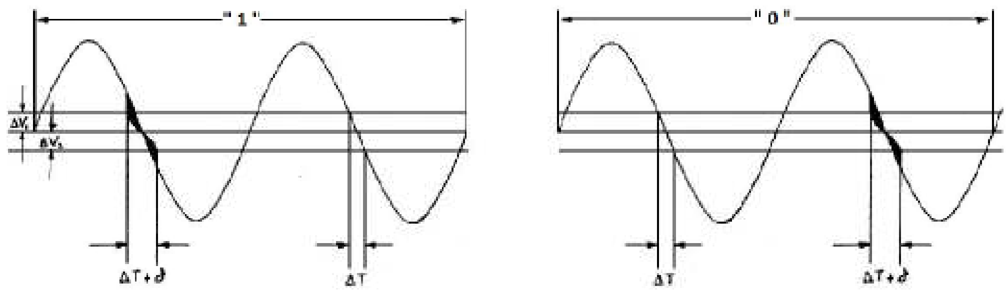



Fig. 2: TWACS outbound signal-bit definitions

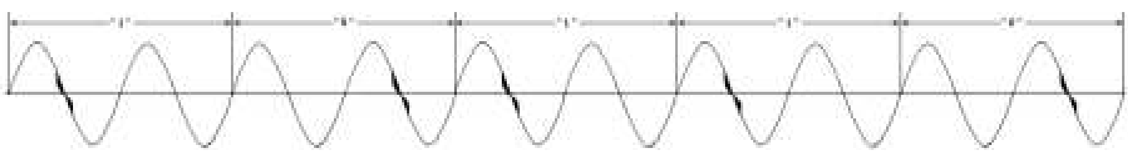


Fig. 3 TWACS outbound signal for bit pattern "10110"

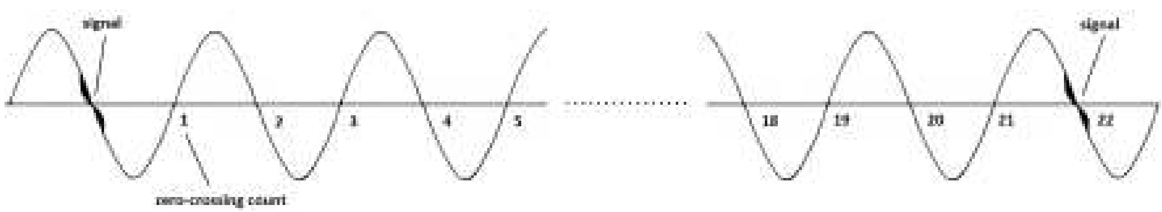



Fig. 4: Proposed outbound signal for decimal 22

frequency) provided by the TWACS, it is much higher than the bit rate of $8\times10^{-4}$ bps provided by the Turtle system. Further, in the proposed method there are only two voltage disturbances in the 50-cycle interval, whereas in the TWACS there will be seven voltage disturbances in the 14-cycle interval.

**TWACS inbound signal generation:** The TWACS generates the inbound signal by firing a thyristor connected in series with $L_1$, a 450 μH inductor (with a resistance of 0.55 Ω) and this combination is connected across the line and neutral at the end user's Point of Service (POS), as illustrated in Fig. 5. The thyristor is fired approximately 35° before the zero-crossing point of the voltage waveform. Thyristor-1 is fired if the current pulse is to be generated at the end of the positive half-cycle of the voltage waveform and thyristor-2 is fired if the current pulse is to be generated at the end of the negative half-cycle of the voltage waveform. The thyristor self-commutes a little past the voltage zero-crossing point when the current drops to zero. This firing produces a current pulse for about one half-cycle duration and the current pulse has a spectral component of approximately 400 Hz. The detector at

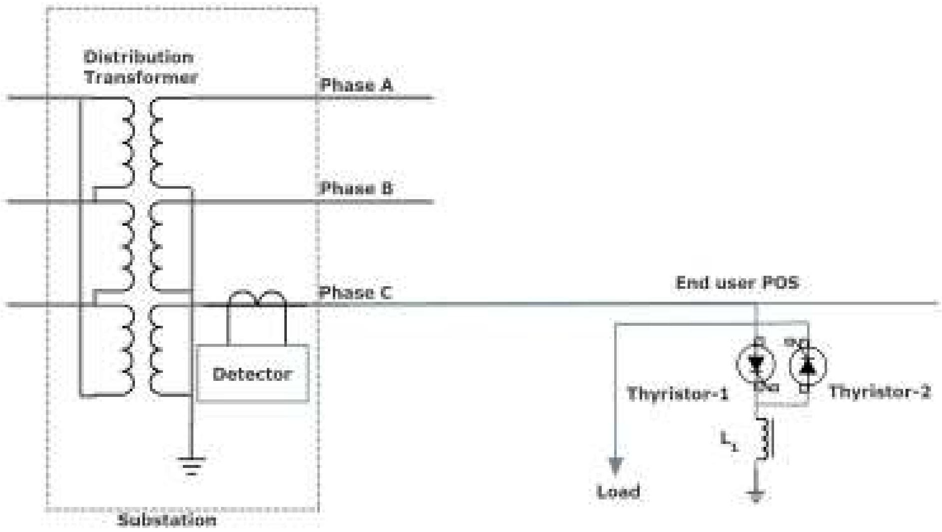



Fig. 5: TWACS inbound signal generation-schematic diagram

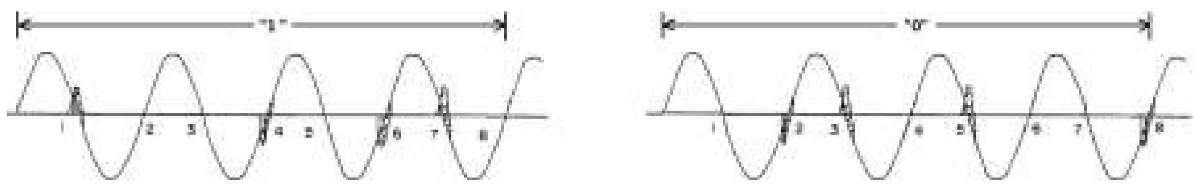



Fig. 6: TWACS inbound signal-bit patterns


Fig. 7: TWACS inbound signal for bit pattern "10011"

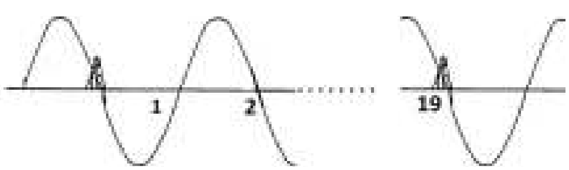



Fig. 8: Proposed inbound signal for decimal 19

the substation looks for spectral content in 200-600 Hz range for an indication of the inbound signal. The bit "1" or "0" is defined by a combination of a number of current pulses within four cycles of the 50-Hz waveform. Bit "1" is defined by current pulses at zero-crossings 1, 4, 6 and 7 and bit "0" is defined by current pulses at zero-crossings 2, 3, 5 and 8, respectively as shown in Fig. 6. The current pulses required to generate the bit pattern "10011" are shown in Fig. 7. Since one bit is transmitted every four cycles, the bit rate considering 50-Hz frequency is 12.5 bps. For each cycle, there is a current pulse and this current pulse results in the generation of current harmonics.

**Proposed method for inbound signal generation:** The proposed method for inbound signal generation is similar to the one adopted for outbound signal generation, except that the inbound signal is generated with a current pulse instead of a voltage distortion. For example, to generate 19 (decimal equivalent of the bit pattern "10011"), the technique shown in Fig. 8 is used. This signaling method generates the first current pulse, starts counting the number of zero-crossings of the voltage waveform and at the 19$^{th}$ zero-crossing, another current pulse is generated to complete signaling, thus requiring only two current pulses for signaling any digit, whereas the TWACS inbound method requires 20 current pulses (four pulses per bit). Thus the proposed method will reduce current harmonics. However, the bit rate depends on the information to be transmitted-larger the decimal value, lesser the bit rate. For example, to transmit a decimal value of 19, half-cycles are required. This is equivalent to transmitting the bit pattern "10011" (binary equivalent of decimal 19) in 19 half-cycles. Considering 50-Hz mains frequency, the resulting bit rate is about 26 bps. If a decimal value of, say 100, is to be transmitted, one hundred half-cycles are required. This is equivalent to transmitting the bit pattern “1100100” (binary equivalent of decimal 100) in 100 half-cycles, resulting in a bit rate of 7 bps.

## RESULTS

The proposed system for low-voltage distribution has been modelled and simulated using SIMULINK. Figure 9 shows the SIMULINK model used for transmission of address of the energy meter. The distribution transformer is modelled as a 440-V three-phase programmable voltage source and its reactance of 0.06 mH is connected in series. The distribution line has been modelled with an inductance of 0.4 mH and a resistance of 0.235 Ω. The loads are modelled as one three-phase 2000 W load, one three-phase 1000 W and 1000 VAr load and to represent the remaining loads on the line, a dynamic load of 200 kW and 100 kVAr is included.

The noise in low-voltage PLC environment can be classified into five components (Klaus, 2001; Ferreira *et al*., 2010; Zimmermann and Dostert, 2002) as shown in Fig. 10. The Background Noise is classified under two sub-categories, as Colored Noise and Narrowband Noise. The colored noise is produced from the common household appliances such as computers, dimmer or hair dryer and it can cause interference in the frequency range up to 30 MHz. The narrowband noise is mainly caused by shortwave and other radio station signals. The Impulsive Noise is classified under three sub-categories, as Periodic Impulsive Noise Synchronous to the mains voltage, Periodic Impulsive Noise Asynchronous to the mains voltage and Asynchronous Non-periodic Impulsive Noise. The periodic impulsive noise synchronous to the mains voltage is caused by power electronic devices. The periodic impulsive noise asynchronous to the mains voltage is mainly generated by the fast switching of equipments such as switching power supply. The asynchronous non-periodic impulsive noise is also known as random impulse noise and is mainly generated by electrical equipment switching pulses at the closing and opening instances. These noise sources have been modelled as Noise Generator and the details of the model are shown Fig. 11 along with the noise waveform generated.

**Address generation by the substation:** The voltage disturbance at the source is introduced by switching ON the thyristor_M at about 5° before the negative-going zero-crossing of the voltage waveform, as implemented in the TWACS. This disturbance is sensed at the load side by the Detector located in the energy meter of each end user. After counting the required number of zero-crossings (for the address), another voltage disturbance is introduced at the source. On sensing the second voltage disturbance, all the detectors stop counting and the number of zero-crossings accumulated so far is taken as the address of the energy meter. Only the energy meter whose address is the same as the accumulated zero-crossings count, will respond.

**Reading transmission by energy meter:** As shown in Fig. 12, the method used for sending the signal is based on switching ON the gate turnoff thyrisor located in the energy meter at the end user point, for a short duration at approximately 30° before negative-going zero-crossing of the voltage waveform as implemented in the TWACS. The resulting current pulse is sensed at the substation. The detector at the substation starts counting the voltage zero-crossing and when the number

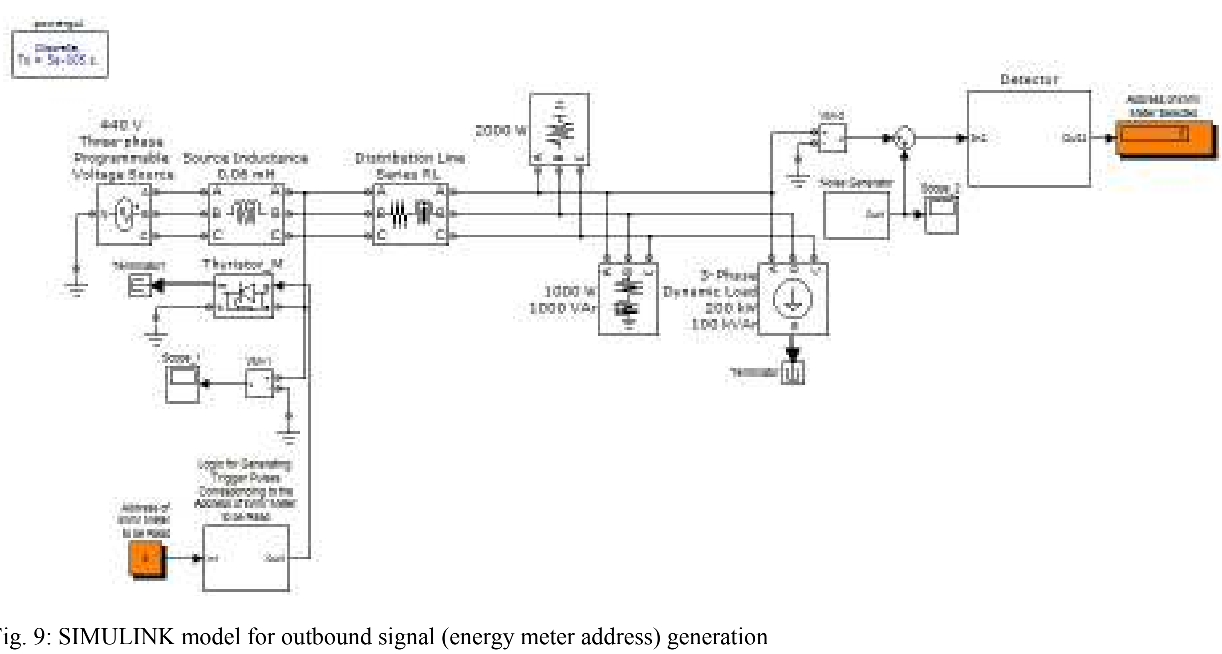



Fig. 9: SIMULINK model for outbound signal (energy meter address) generation

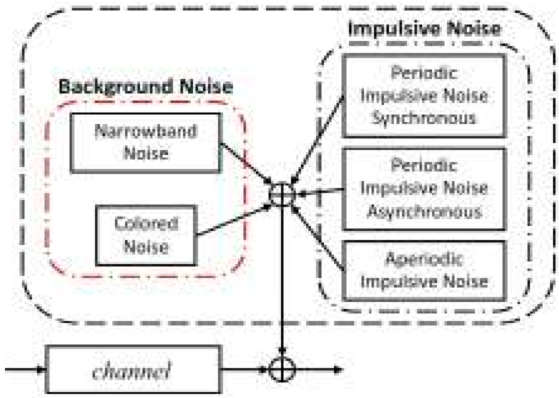



Fig. 10: Classification of power line noise

of accumulated zero-crossing becomes equal to the meter reading, another current pulse is generated by switching ON the gate turnoff thyristor in the energy meter. On sensing this current pulse, the detector at the substation stops counting the voltage zero-crossing and the accumulated count is taken as the meter reading.

The sequence of interaction between the substation and the end user energy meter for determining the meter reading is shown in Fig. 13.

**Comparison of harmonic distortions:** The IEC standard IEC6100-4-7:2002 specifies the use of the 10 cycle-period as the window size while measuring harmonics using Fast Fourier Transform (FFT). The voltage harmonics generated during TWACS outbound signal transmission is shown in Fig. 14. The total voltage harmonics distortion for a 10-cycle window is 0.84%.

The voltage harmonics generated by the proposed system is shown in Fig. 15. The total voltage harmonic distortion introduced when the voltage disturbance is inside the 10-cycle window is 0.17%, otherwise it is zero.

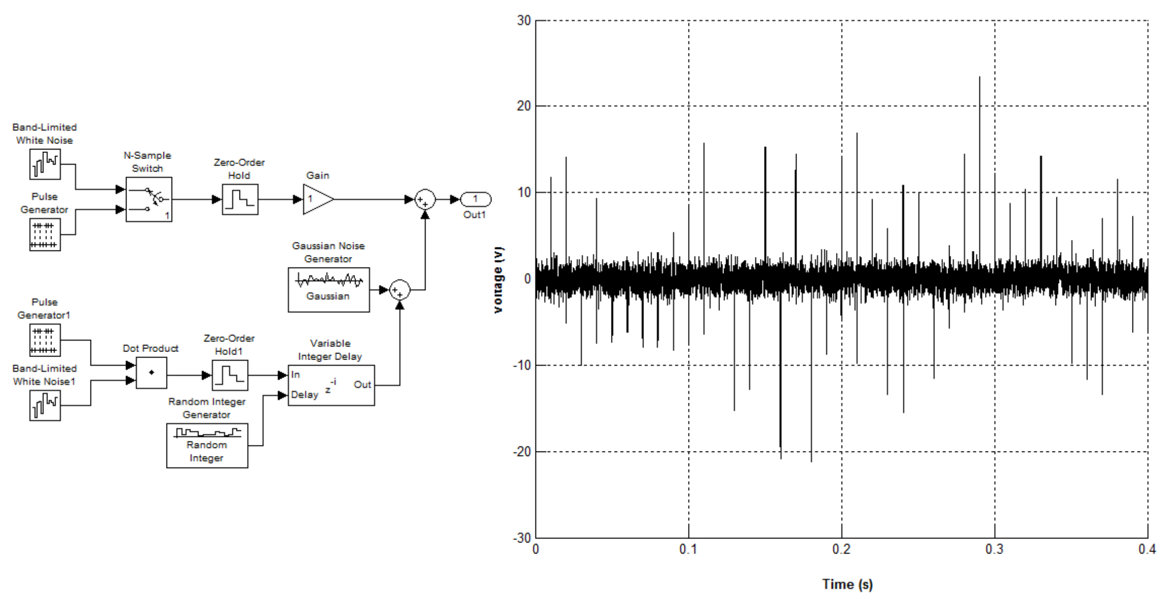
The current harmonics generated during TWACS outbound signal transmission, as measured at the substation is shown in Fig. 16. The total current harmonic distortion for a 10-cycle window is 2.07%.

The current harmonics generated by the proposed system is shown in Fig. 17. The total current harmonic distortion introduced when the current pulse is inside the 10-cycle window is 1.10%, otherwise it is zero.

**Verification of adequacy of baud rate:** The proposed system depends on counting the number of zero-crossing of the voltage waveform to broadcast the address and for determining data at each address. Since the supply frequency is 50 or 60 Hz, the number of voltage zero crossing per second is 100 or 120, respectively.

A typical bi-monthly consumption data for residents in an area supplied by a 500 kVA transformer is given in Table 1.

For the supply frequency of 50 Hz, assuming that the individual energy meters are designated addresses from 1 to 600, it takes 53 min to complete one cycle of bi-monthly readings for the raw data given in Table 1, based on calculations done. However, this calculation does not take into account any coding scheme or retransmission of data that will be required to ensure integrity of data. This calculation has been done to demonstrate that with this method, it is possible to read all the meters connected to a typical distribution transformer, at least once a day.




(a) (b)

Fig. 11: Power line noise model, (a) SIMULINK model, (b) noise waveform

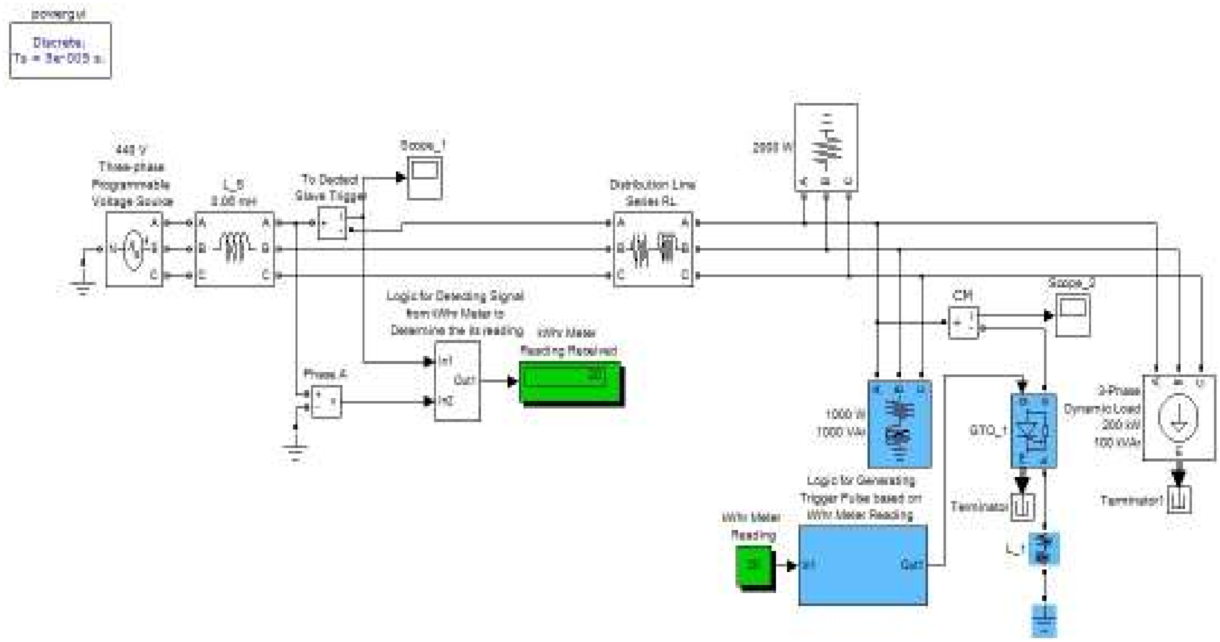



Fig. 12: SIMULINK model for energy meter reading transmission

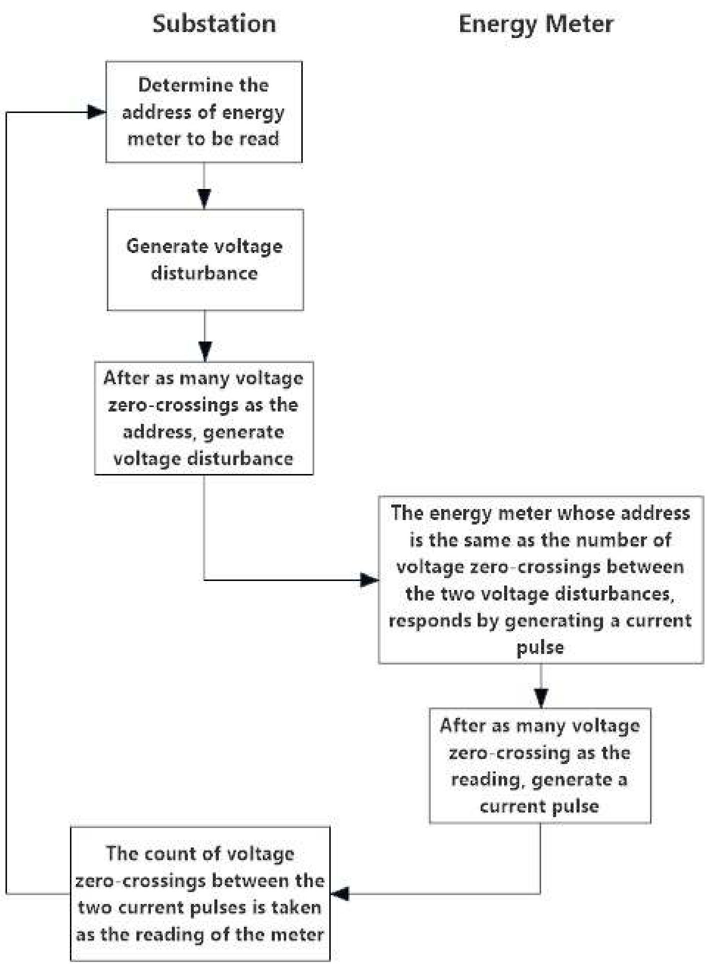



Fig. 13: Flow chart showing sequence of interactions between substation and energy meters

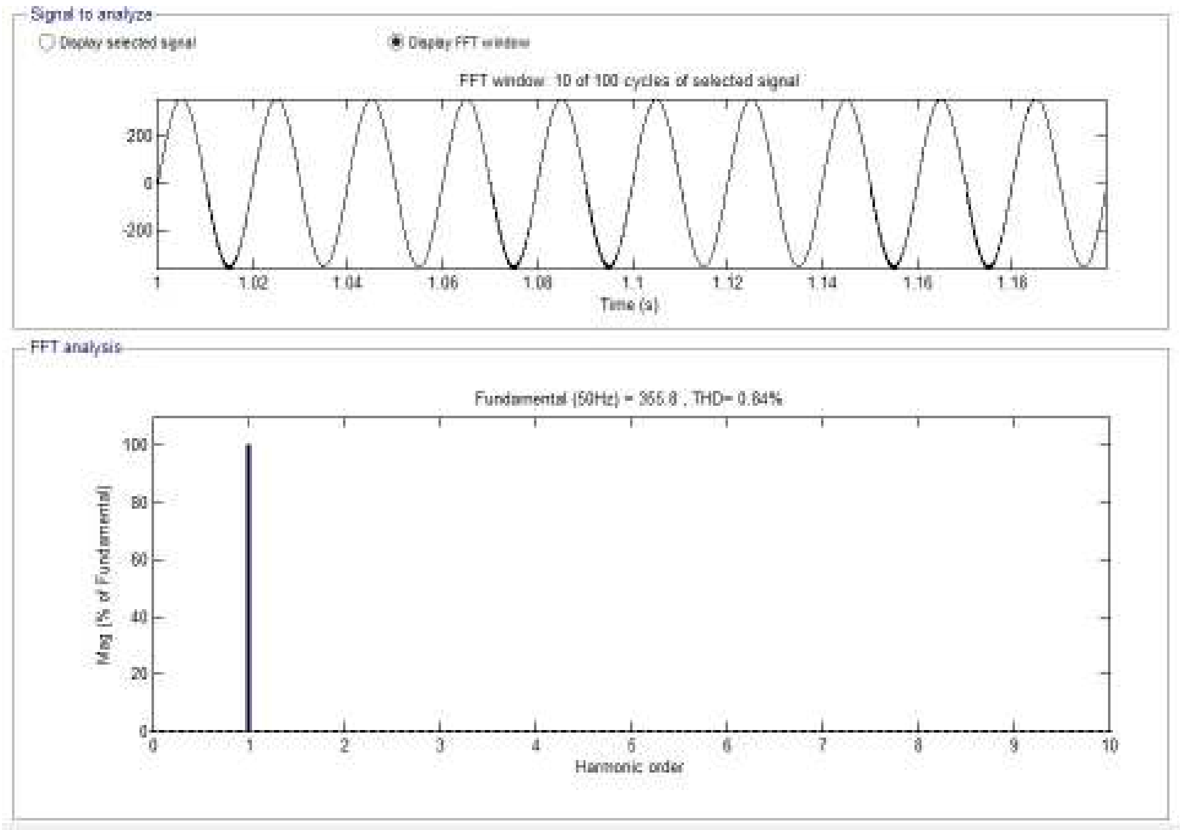



Fig. 14: Voltage harmonics in TWACS outbound signal

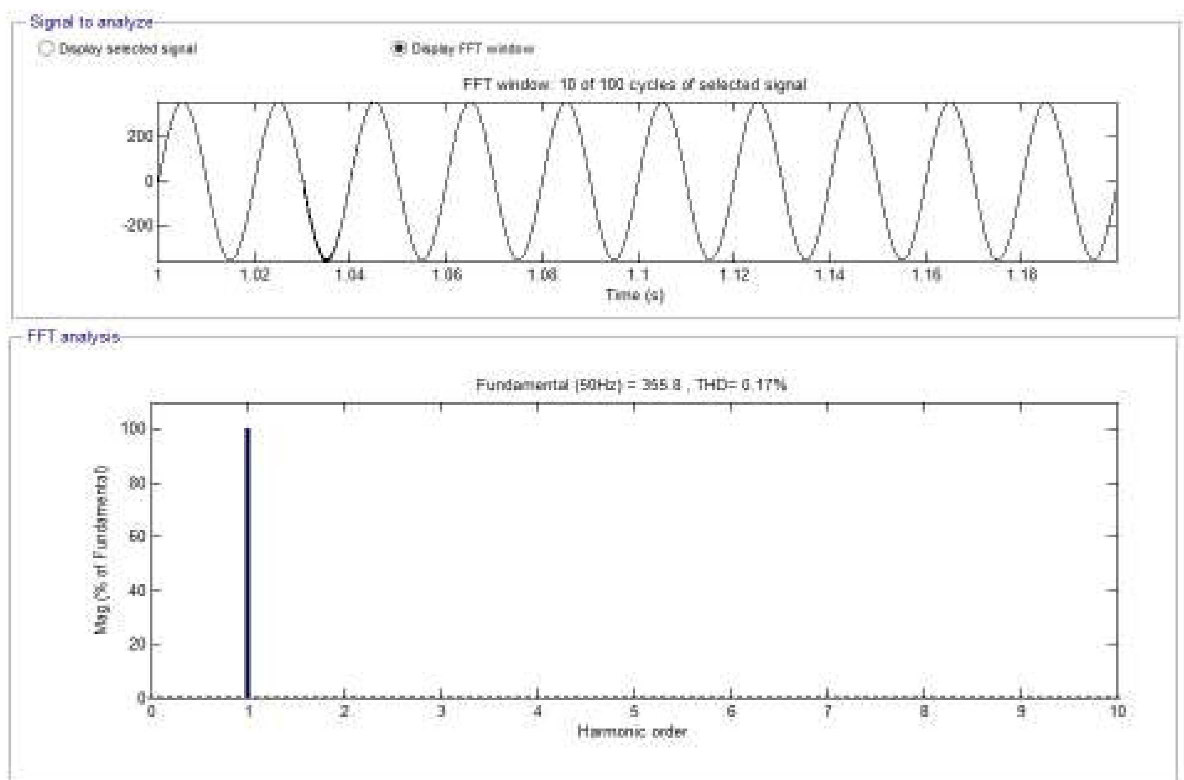



Fig. 15: Voltage harmonics in the proposed outbound signal

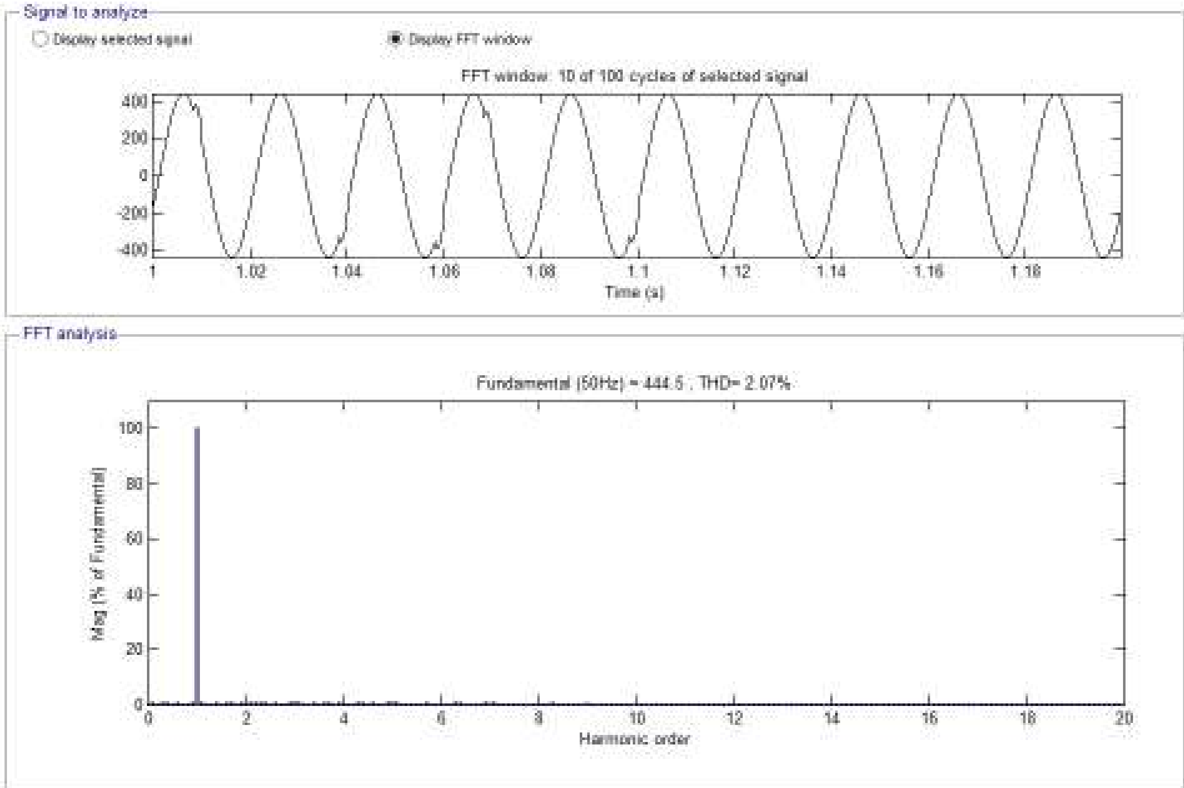



Fig. 16: Current harmonics in TWACS inbound signal

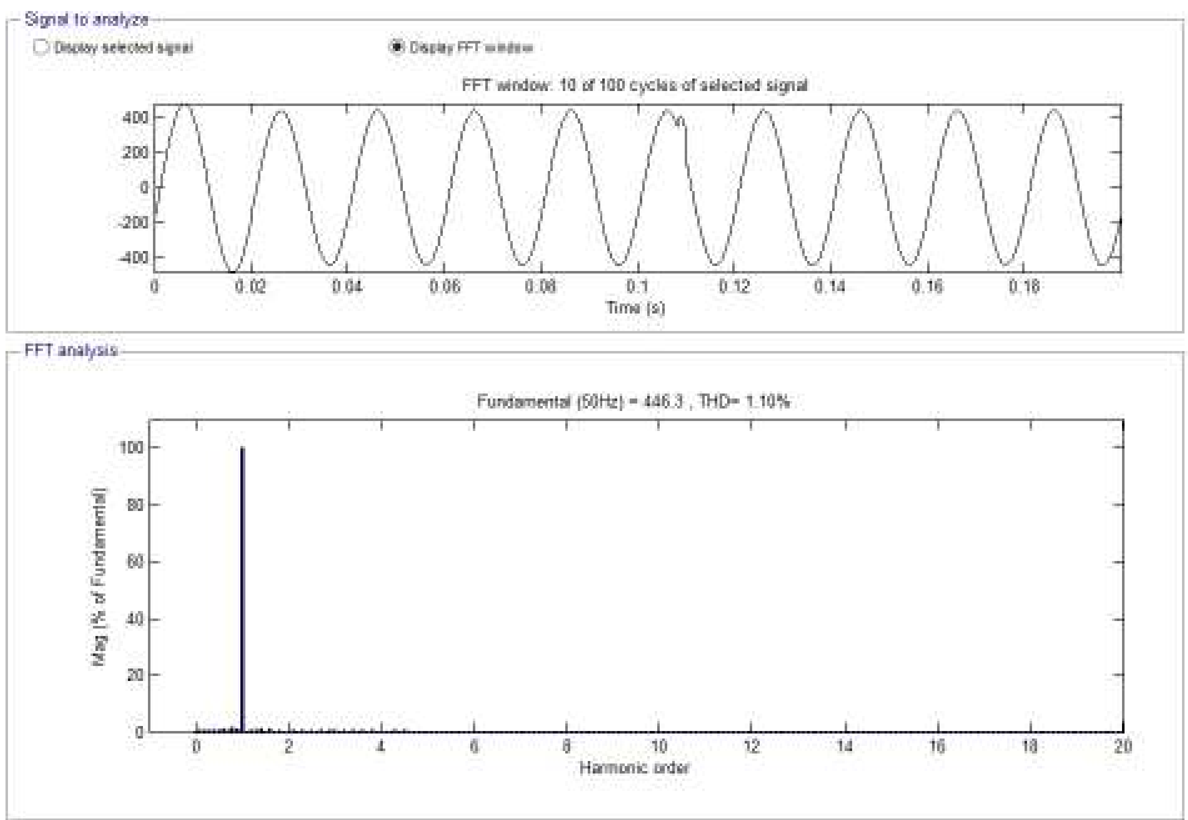



Fig. 17: Current harmonics in the proposed inbound signal

Table 1: Actual energy consumption details provided by the utility

| | Number of consumers based on energy consumption range (in kWhr) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 01 to 50 | 51 to 100 | 101 to 150 | 151 to 200 | 201 to 250 | 251 to 300 | 301 to 350 | 351 to 400 | 401 to 450 |
| LA1A-domestic | 37 | 77 | 85 | 85 | 81 | 60 | 30 | 28 | 24 |
| LC2A-publ light suppl-corporation | 1 | | | | 2 | | | | |
| LV2A-publ light suppl-village panchayat | | | | | | | | | |
| LM2C-actual places of public worship | | | | | | | | | |
| LM3B-industries -metro | | | | | | | | | |
| LN3B-industries-non metro | | | 1 | | | | | | |
| LM51-commercial | 35 | 10 | 5 | 4 | | | | 1 | |
| Total | | | | | | | | | |

| | Number of consumers based on energy consumption range (in kWhr) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 451 to 500 | 501 to 550 | 551 to 600 | 601 to 650 | 651 to 700 | 701 to 750 | 751 to 800 | above 800 | Total |
| LA1A-domestic | 16 | 3 | 3 | 1 | 3 | 0 | 2 | 2 | 537 |
| LC2A-publ light suppl-corporation | | 2 | | | | | | | 5 |
| LV2A-publ light suppl-village panchayat | | | | | | | | | |
| LM2C-actual places of public worship | | | | | | | | | |
| LM3B-industries -metro | | | | | | | | | |
| LN3B-industries-non metro | | | | 1 | | | | 1 | 3 |
| LM51-commercial | | | | | | | | | 55 |
| Total | | | | | | | | | 600 |

Area: Extension-1; Transformer rating: 500 kVA; Tariff code; Month 06/2012

## CONCLUSION

This study has presented a novel method for automated meter reading based on power line based communications and has proposed the application of this technique for automated meter reading. This method is based on the modification of the most popular PLC based AMR system today, the TWACS. The proposed method uses the techniques employed by TWACS for generating signals, but these signals are used only as markers and not for transmitting information-information is transmitted by counting the zero-crossing of the voltage waveform between two successive markers. The system has been modelled and simulated using SIMULINK. The simulations results show that there is a reduction in voltage harmonics from 0.84 to 0.17% and in current harmonics from 2.07 to 1.10%. Though the bit rate is lower than that provided by the TWACS, it has been shown that this bit rate is adequate for the intended application of automated meter reading. Further work needs to be taken up for encrypting information for data security.

## REFERENCES


Allan, R., 2006. Overview of automatic meter reading for the water industry. Proceeding of the 31st Annual Queensland Water Industry Workshop, University of Central Queensland, Rockhampton.

Anatory, J., M.V. Ribeiro, A.M. Tonello and A. Zeddam, 2013. Power-line communications: Smart grid, transmission and propagation. J. Electr. Comput. Eng., 2013(2013): 2, Article ID 948598.

Cavdar, I.H., 2004. A solution to remote detection of illegal electricity usage via power line communications. IEEE T. Power Deliver., 19(4): 1663-1667.

David, W.R. and R.W. Michael, 2011. Ultra low frequency power-line communications using a resonator circuit. IEEE T. Smart Grid, 2(1): 41-50.

Ferreira, H.C., L. Lampe, J. Newbury and T.G. Swart, 2010. Power Line Communications: Theory and Applications for Narrowband and Broadband Communications over Power Lines. Wiley, West Sussex.

Galli, S., A. Scaglione and W. Zhifang, 2011. For the grid and through the grid: The role of power line communications in the smart grid. P. IEEE, 99(6): 998-1027.

Ghajar, R.F. and J. Khalife, 2003. Cost/benefit analysis of an AMR system to reduce electricity theft and maximize revenues for Électricité du Liban. Appl. Energ., 76(1-3): 25-37.

Hawkins, A., 2010. Evolution of AMI technologies and enablement of smart grid. Proceeding of the IEEE PES Transmission and Distribution Conference and Exposition, pp: 19-22.

Ipakchi, A. and F. Albuyeh, 2009. Grid of the future. IEEE Power Energy M., 7(2): 52-62.

Khalifa, T., K. Naik and A. Nayak, 2011. A survey of communication protocols for automatic meter reading applications. IEEE Commun. Surv. Tu., 13(2): 168-182.

Klaus, D., 2001. Power Line Communications. Prentice Hall PTR, New Jersey.

Mak, S.T. and R.L. Maginnis, 1995. Power frequency communications on long feeder and high levels of harmonic distortion. IEEE T. Power Deliver., 10(4): 1731-1736.

Pedro, A., 2009. Reducing Technical and Non-Technical Losses in the Power Sector. Background Paper for the World Bank Group Energy Sector Strategy, World Bank, Washington.

Robert, T., 2012. AMR for a Cooperative World. Electric Energy Publications Inc., Canada. Retrieved from: http://www.electricenergyonline.com/?page=show_article&mag=24&article=185.

Wilson, X. and W. Wencong, 2010. Power electronic signaling technology-a new class of power electronics applications. IEEE T. Smart Grid, 1(3): 332-339.

Zimmermann, M. and K. Dostert, 2002. Analysis and modeling of impulsive noise in broad-band powerline communications. IEEE T. Electromagn. C., 44(1): 249-258.