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A Low-Cost AMR Technology Based on Power Line Signaling

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Abstract

AMR is a technology for reading an energy meter remotely. Initially AMR solutions were developed to overcome the problems of manual reading. Today AMR has become a necessity for effective energy management. The effectiveness of AMR to detect theft, and any unmetered consumption is enormous. Though the cost of PLC based AMR system has been reducing, the cost is still considered high. The proposed method does not require power line modem and decoupling circuit; it uses power line signaling methods, along with counting of zero-crossings of voltage waveform, to provide a low-cost technology.

Key words: Power line communication, automated meter reading, power line signaling

Introduction

Automatic Meter Reading (AMR), also called Automated Meter Reading, refers to an energy meter reading system that makes it possible to read electronic energy meters remotely. According to Allan Readdy [1], 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.

Electric utilities have long sought to find ways to reduce costs associated with energy meter reading. In the early 1980s, hand-held meter reading devices were deployed to replace manual recording of meter reading. With Touch-Read Meter, a meter reader carries a handheld data collection device, and readings are automatically collected by placing a wireless probe close to the meter. With Walk-by Meter, the meter reader does not need to be at the meter location. With a handheld RF device, reading can be obtained several houses away and this speeds up data collection. With Drive-by Meter, the meter reader remains in a vehicle and the readings are collected as the vehicle is moving. While these systems significantly improved meter reading accuracy, site visits were still needed to obtain readings. Robert Turnbull [2] mentions that in the 1980s, fixed wireless infrastructure was built to allow metering data to be read directly into the billing system. Based on a survey conducted by Frost and Sullivan [3], in the 1990s, the high cost of proprietary fixed wireless infrastructure forced the industry to develop new AMR systems built around public wireless networks. Duringthe past twenty years, metering technology has evolved from AMR to Advanced Metering Infrastructure (AMI), which refers to the combination of the electronic meters with two-way communications technology for information, monitoring and control. The evolution of smart meter technology along with functionality, according to Edison Electric Institute [4], is shown in Fig. 1.

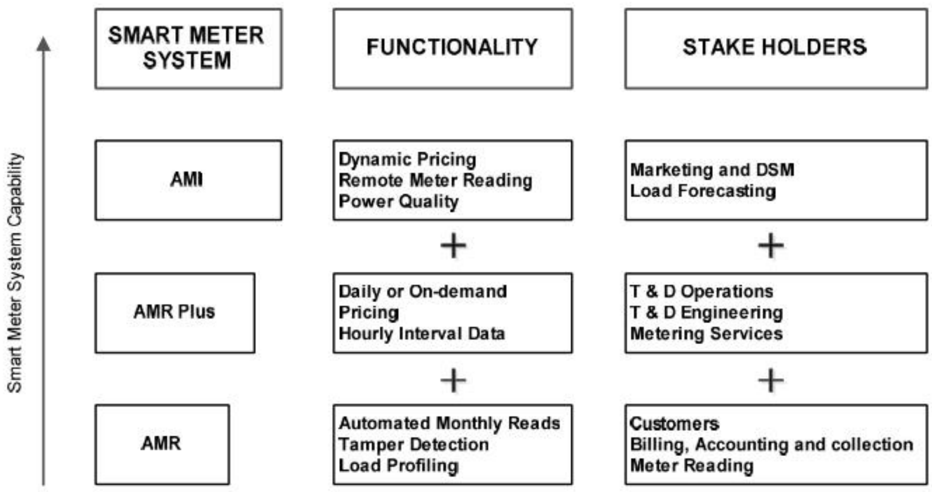

Figure 1: Evolution of AMR Technology

Tarek Khalifa, et al. [5] mentions that though initially, AMR solutions were primarily developed to overcome the problems of manual reading, today, AMR has become a necessity for effective energy management and energy accounting. Distribution sector is considered to the weakest link in the entire power sector, involving a large network, and requires network management over a vast area. Theft, pilferage and network losses are the maximum in this segment. Revenue sustainability is an imperative requirement for running an electricity distribution network. According to Pedro Antmann [6], Hakki Cavdar [7], and Raymond F. Ghajar [8], the effectiveness of AMR to detect and discourage theft and other ways of unmetered consumption is enormous, based on the recent experience of developing countries.

Due to the emphasis on energy management, AMR technology has shown remarkable changes over the years. Since the major part of an AMR system is the underlying communication technology, the AMR system can be classified under four major types of communication networks: Power line carrier (PLC), Cellular network, telephone/Internet and short range radio frequency.There are also AMR systems that use a combination of these basic communication networks. The report by Dimitropoulos [9] shows that, based on existing communication technologies, the

mixedcommunication technology options that appear appropriate today for either rural (low density) or urban (high density) areas are a combination of PLC and WiMax, and a combination of Broadband and GSM (3G).
Dedicated communication infrastructure for metering only is likely to be very expensive; using an existing network is likely to be a more cost effective solution. PLC based AMR system is the utility company's preferred technology. The advantages of PLC technology include leveraging the use of existing utility infrastructure, improved cost effectiveness for rural lines, more effective in challenging-terrain, and the capability to work over long distances. Besides these reasons, there is concern on human exposure to RF sources. In its report [10], *Health Impacts of Radio Frequency Exposure from Smart Meters*, the California Council on Science and Technologyprovides the following guide lines:
"As wireless technologies of all types increase in usage, it will be important to: (a) continue to quantitatively assess the levels of RF emissions from common household devices and smart meters for which the public may be exposed, and (b) continue to investigate potential thermal and non-thermal impact of such RF emissions on human health. Consideration could be given to alternative smart meter configuration (such as wired) in those cases where wireless meters continue to be of concern to consumers."
In addition to the benefits, the PLC technology provides inherent security. In the context of AMR, security refers to the possibility that a metering device getting disabled so as to prevent communication of data. Only the PLC option with communication interface embodied within the device appears to be difficult to tamper with.
The disadvantages of PLC technology include less bandwidth and throughput, and higher cost, particularly in urban and semi-urban deployments.
In this paper, a low-cost PLC based AMR technology is presented. Section II describes the contributions made by this paper, while Section III provides a brief review of the PLC technologies in general, and Section IV presents the modern PLC technologies used for AMR. Section V introduces the proposed technology, and the technology is described in detail in Section VI. Finally, the conclusion and further work are discussed in Section VII.

Contributions

Unlike the existing PLC technologies where data is superimposed on the 50/60 Hz ac voltage, the proposed new technology provides a low-cost method for implementing AMR solutions based on power line signaling (or mains signaling), using the count of zero crossings of line voltage as information to be transmitted. The implementation does not require any power line modem (which is an expensive component of the existing automated meters), and also does not require any decoupling circuit between the power line and the meter, resulting in substantial cost savings.
This new technology is recommended for power line communication between the secondary of distribution transformer and electronic energy meters installed at the consumer premises. Then, from the secondary of distribution transformer, another means of communication, such as GSM or GPRS is to be used for communicating

with the central station, as shown in Fig. 2. According to VehbiGungor, et al. [11],AMR systems that employ a similar architecture – PLC technology for communication between meters and data concentrator, and GPRS technology for transferring data from the data concentrator to the utilities data centre, have been successfully deployed, and are in use today.

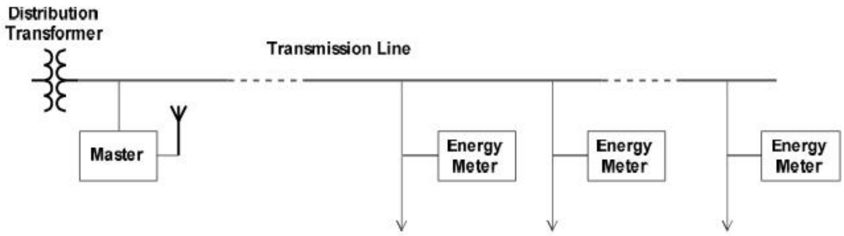

Figure 2: Schematic Diagram of the Proposed Automated Metering System

This paper makes the following contributions:
1. A cost effective PLC technology is made available for urban and semi-urban areas,
2. A cost-effective PLC technology based AMR solution is made available for small rural consumers,
3. An alternative PLC based AMR solution is made available to consumers who are concerned with exposure to RF emissions, and
4. Developing countries can increase penetration of AMR deployments.

PLC Technologies

Power line carrier communications (PLCC) over HT lines is an old and established practice, but the use of LT segment below the distribution transformer (DT) for communication purposes represents new challenges. Since power lines are designed for transmission of power at 50/60 Hz, the use this medium for data transmission presents some technically challenging problems. Besides large attenuation, power lines are one of the most electrically contaminated environments, which make communication extremely difficult.

The IEC standard 61000-2-1, "*Description of the Environment: Electromagnetic Environment for Low-frequency Conducted Disturbances and Signaling in Power Supply Systems*",describes Mains Signaling Systems as those that use the power distribution network for the transmission of signals, and these signals can be classified into four types according to the transmission frequency or the kind of signal:

a) Ripple carriersystems,using sinusoidal signals in the range of 110 Hz to 2000 Hz,
b) Medium-frequency power line carrier systems, using sinusoidal signals in the range of 3 kHz to 20 kHz,

c) Radio frequency power line carrier systems, using sinusoidal signals in the range of 20 kHz to 150 kHz, and
d) Mains-mark systems, using non-sinusoidal marks on the mains voltage waveform.

Ripple carrier signaling (RCS) has been used since about 1930s. Since RCS was designed to allow information flow over the transformers between the medium-voltage and low-voltage levels without any specific coupling measures, it works at low frequencies close to the power frequency , and information has to be fed with a high transmit power. The data rate is low and information can flow from the power supply company to the consumers only. Though remote metering with RCS is not possible because of unidirectional functionality, this technology has been found to be adequate for management of load distribution.

Current Amr Technologies Based on PLC

The fundamental principle in transmitting information through power line for automated metering involves superimposing a high frequency signal over the 50/60 Hz power signal. The use of distribution networks for communications has been increasing, and to limit the radiation emission of power lines three standardization bodies – IEC, CENELEC and IEC have formulated international standards. The European CENELEC standard EN 50065, that specifies the use of frequency range 3 to 148.5 kHz, has been in force since 1991. This standard differs considerably from regulations applicable in the United States or in Japan, where a frequency range of approximately 500 kHz is made available for power line communications.

As given by Klaus Dostert [12], the EN 50065 standard specifies the frequency use and the admissible signal levels for communication over power lines below long-wave radio broadcast band. As shown in Fig. 3, the frequency band is divided into two parts – frequencies below 95 kHz (A band) are reserved for PSUs, while the range from 95 kHz to 148.5 kHz (B, C, and D bands) is for private use mainly within buildings for automation tasks. Amaximum signal level of 122 dBμV, equaling 1.25 V, applies to the B, C, and D bands, while the level in the A band may be 134 dBμV, equaling 5V at 9 kHz and is lowered to 120 dBμV, equaling 1 V up to 95 kHz. The current technologies based on EN 50065 allow bidirectional data traffic at rates up to about 128 kbps, depending on the modulation and coding methods adopted.

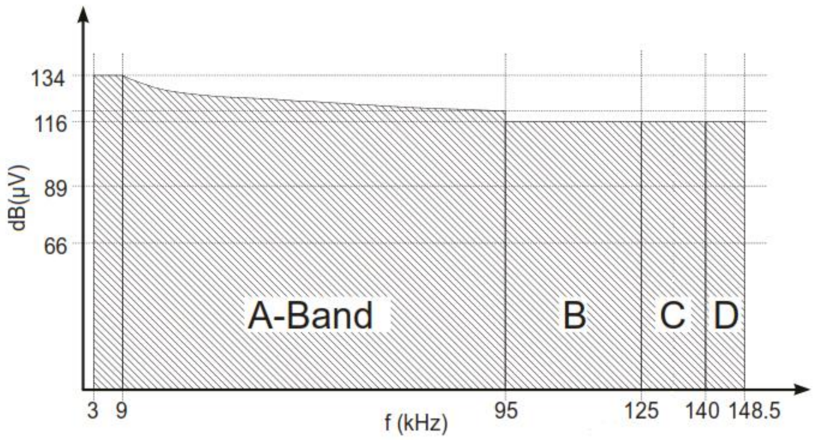

Figure 3: Frequency Ranges and PLC Signal Limits specified in CENELEC Standard EN 50065 Standard

Usually, narrowband PLC refers to low rate digital communication utilizing the frequency below 150 kHz in Europe based on CENELEC standard, and below 450 kHz in the USA and some Asian countries. According to Hendrik C. Ferreira, et al. [13], the Wideband or Broadband PLC is used to achieve higher data rates, and there is delay in implementation of this technology due to slow development of standards acceptable to all participants

The Proposed PLC Based Low-Cost Amr Technology

Even though power line communications is attractive for automated electrical metering, since the power lines are designed for power delivery rather than communication purposes, the characteristics of the power line such as time-varying frequency-dependent channel attenuation of up to 60 dB, reflections from non-terminated points resulting in multipath fading, and various types of noise, pose challenges. The random nature in switching of loads makes the changing channel condition more unpredictable. The reflections are caused by impedance mismatches at joints and terminations. In contrast to many other communication channels, the noise in power line cannot be described by an additive white Gaussian model. According to Zimmerman, et al. [14], there are five types of noises on power lines, and the most unfavourable of these is the asynchronous impulse noise caused by switching of loads. Dai, et al. [15], shows that these impulses have very short durations in the range of a few micro seconds to a few milliseconds, and are random in occurrences. For these reasons, the existing technologies based on modulation principles result in higher product costs. The proposed technology uses mains signaling or power line signaling which does not require the adoption of standard modulation techniques, and hence the product cost is lower.

The IEC standard 61000-2-1 considers several kinds of signals under mains-mark systems, wherein non-sinusoidal marks on voltage waveform are used:

i. Long pulses in terms of voltage depressions of 1.5 ms to 2.0 ms (preferably at the zero-crossing of the voltage wave in order to avoid flicker phenomena),
ii. Short pulses In the form of notches of the voltage wave with a duration of 20 µs to 50 µs, and
iii. Pulses of the fundamental frequency 50/60 Hz with a duration of half a cycle or one cycle.

According to Xu, at al. [16], with the help of power electronics, it is possible to mains-mark signals in the power distribution lines directly, resulting in much simpler PLC technologies. The general principle is that a thyristor is used to create a waveform disturbance such as a very small but detectable voltage reduction. The existence of this voltage reduction implies an event, and if there is no voltage reduction, it implies that there is no event. Some of the techniques based on this method are Zero-Crossing Shifting Technique, Zero-Crossing Distortion Technique, and Ripple Signaling Technique. Wilson Xu [17] mentions that, zero-crossing distortion technique has been chosen as the means to broadcast a signal to all distribution feeders for detection of island condition in the case of distributed generation.

Description of the Proposed Technology

The proposed technology uses the zero-crossing distortion technique along with zero-cross counting as the basis for identifying an energy meter in the distribution network.MATLAB/Simulink has been used to conduct the feasibility analysis. A 11 kV/415 V, 3-phase distribution transformer is connected to the distribution line, and Z_s represents the lumped equivalent of a typical distribution line, with an inductance of 0.4 mH and a resistance of 0.235 Ω.The principle of zero-cross distortion method is shown in Fig. 4. Athyristor (R_{ON} = 1 m Ω, V_f = 0.8 V, with a snubber of resistance 100 Ω and capacitance 0.1 µF) is connected between the line and neutral (which is grounded). A series inductor is not required to limit the short-circuit current, since the thyristor will be switched on when the line voltage is low (in the range of 10 V to 20 V), and the internal resistance of the thyristor will limit the current. The thyristor is switched on a few milliseconds before the voltage crosses zero creating a momentary short circuit. The thyristor is automatically switched off when the current reaches zero and a reverse-polarity voltage appears across its anode and cathode. The voltage waveform shown in the Fig.5 indicates that there is a small distortion near the negative-going line voltage. The waveform distortion is the signal generated by the master(data concentrator) located at the secondary of the distribution transformer to invite the attention of all the energy meters connected in the distribution line, with each energy meter assigned a unique address. After the signal is generated, the master and all the energy meters start counting the number of zero-crossings in the line voltage. If the master wants to address a particular energy meter, say whose address (*M_addr_reg*) is 15, the master creates another waveform distortion 15 zero-crossings after the first waveform distortion. When second signal is detected by all the energy meters, the energy meter whose address is 15alone is chosen for determining itsdata(*S_data_reg*), and now the master starts to increment a counter (*M_data_counter*) for every zero-crossing.

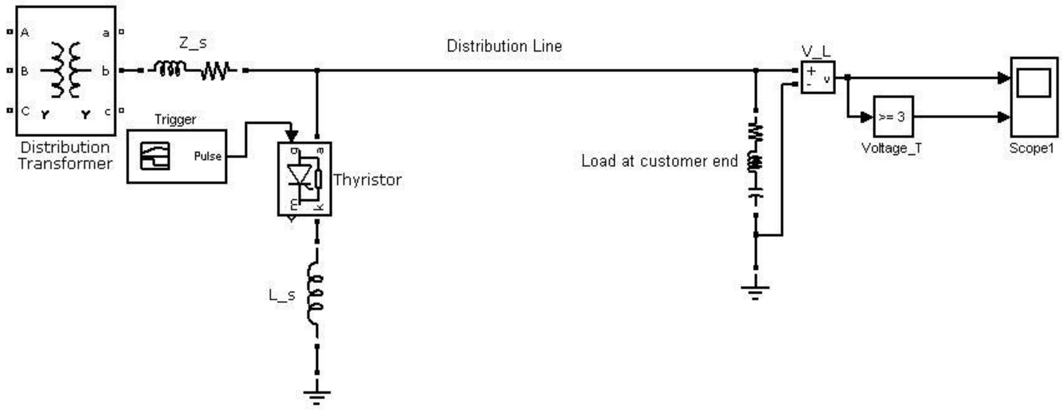

Figure 4: Schematic Diagram for Generating Zero-crossing Voltage Waveform Distortion

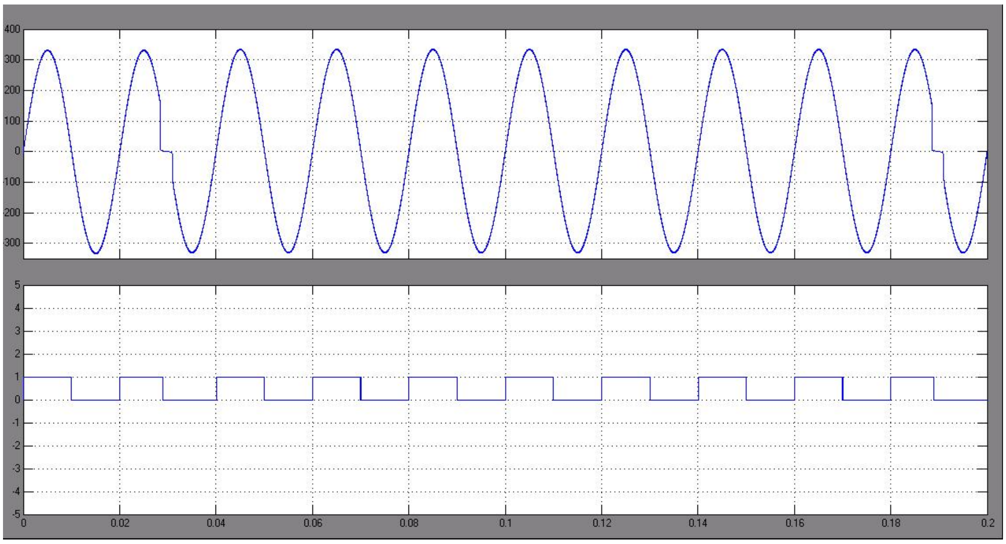

Figure 5: Simulation Waveforms Showing the Zero-cross Distorted Voltage Waveform and the Corresponding Zero-cross Detector output (X-axis: time is seconds, Y-axis: top graph - line voltage in Volts, bottom graph – logic levels 0, 1)

Assuming that the data to be transferred by the selected energy meter is 47, after as many zero-crossings the energy meter short-circuits the phase and neutral for a very short duration. This short circuit results in a momentary current pulse and this pulse is detected by the master and the master stops incrementing *M_data_counter*. The value stored in the *M_data_counter*, i.e., 47 is the data stored in the energy meter whose address is 15. Now the master repeats this cycle till readings from all energy meters are determined by the master, as shown in Fig. 6.

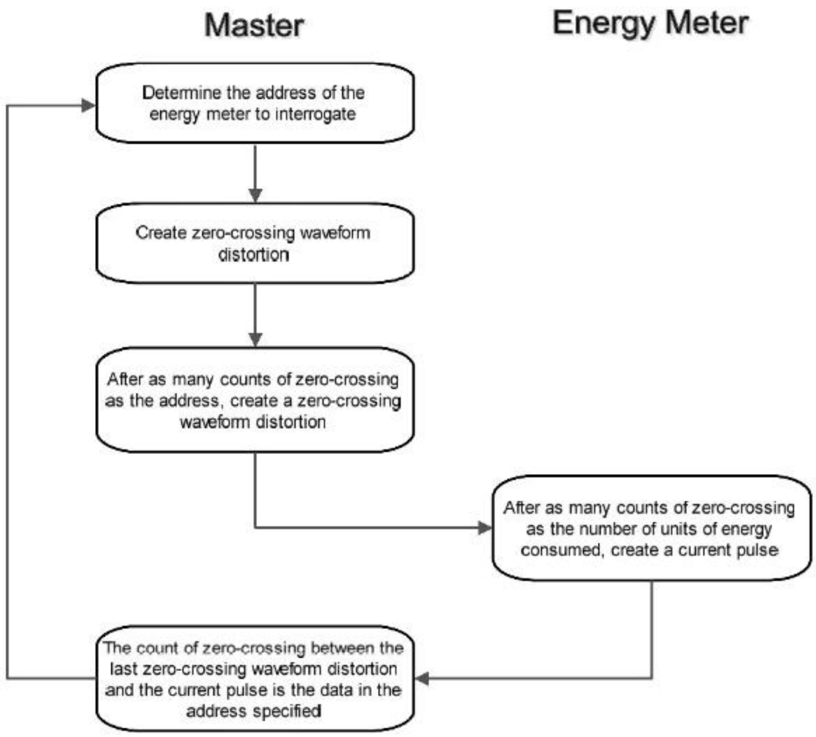

Figure 6: Operation Sequence for Reading Data Stored in the Energy Meter

According to Jouybari-Moghaddam, et al. [18], of the mature power line signaling techniques- ripple control, waveform shift and waveform distortion techniques, considering that the signaling technique should be reliable, low cost and have a fast response, the waveform distortion technique is the most appropriate. Hence the waveform distortion technique has been chosen as a method for generating signals, by the master. In this method, the thyristor is switched on at a predetermined angle before the voltage zero-crossing point. The distortion is sporadic, and can only be detected by using special signal detection techniques. Hence it does not introduce harmonic distortion in a manner that the total harmonic distortion exceeds limits specified for maintaining power quality.

The proposed technology suggests one of the two methods for detecting the signal generated by the master. The first method uses zero-crossing detection technique where a comparator produces a positive voltage if the phase voltage exceeds a small positive threshold voltage. The output of the comparator is a square waveform. The time duration of successive positive voltage outputs of the comparator are compared, and when the difference between two successive time durations is more than a threshold value, it is taken as the signal generated by the master.

The second method subtracts the voltage of two successive cycles, and if the voltage difference (v_{signal}) is more than a threshold value, it is taken as the signal generated by the master. Three detection algorithms are proposed by Wilson Xu [17]. The first algorithm uses the RMS value of the v_{signal} for signal detection and it did not perform reliably in environment with high electrical noise. The other two algorithms are spectral based algorithm and template based algorithm. Based on the observations of Jouybari-Moghaddam, et al. [18], it can be said that the template based method is more reliable in environments with excessive noise pollution.

The structure of networks that use distributed generation for which signal detection algorithms are discussed by Wilson Xu [17], is different from that of the LT distribution network for residential consumers. The voltage and power levels, and network lengths in the case of distribution generation are typically around 22 kV, a few tens of MVA and a few kms, respectively. In the case of LT distribution, the typical values are 415 V, 250 kVA/500 kVA, and a few hundred metres, respectively. Hence the automated meter reading technology proposed here will use the first method of comparing the time durations of two successive positive half-cycles of the voltage waveform to detect signal, and field tests will be conducted to validate the choice.

A. Signal Generated by the Energy Meter

As shown in Fig. 7, the method used for sending a signal is also based switching on a thyristor on the consumer side, to short circuit the phase and line momentarily. This results in a current pulse, as shown in Fig. 8, which can be detected at the secondary of the distribution transformer. For the purposes of simulation, the total load at customer end is chosen to be 100 kVA at 0.8 lagging power factor, and L_s to be 1 mH.

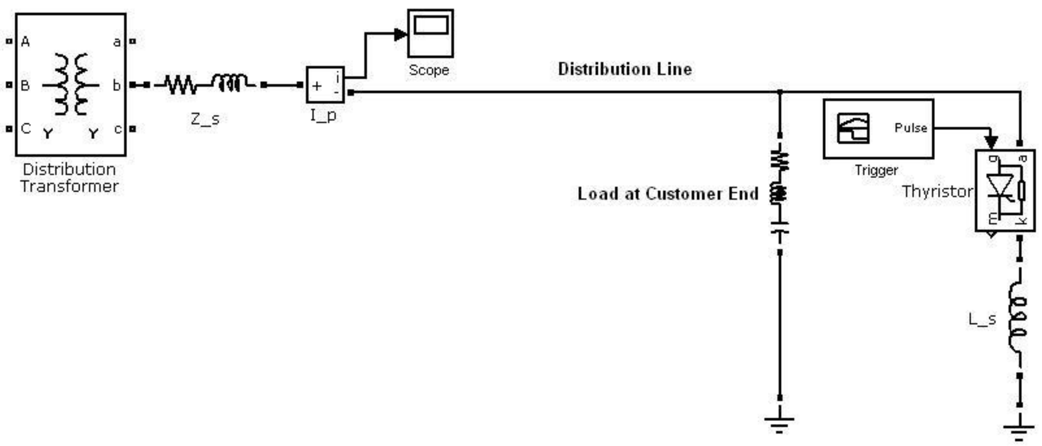

Figure 7: Schematic Diagram for Generating the Current Pulse at the Consumer End

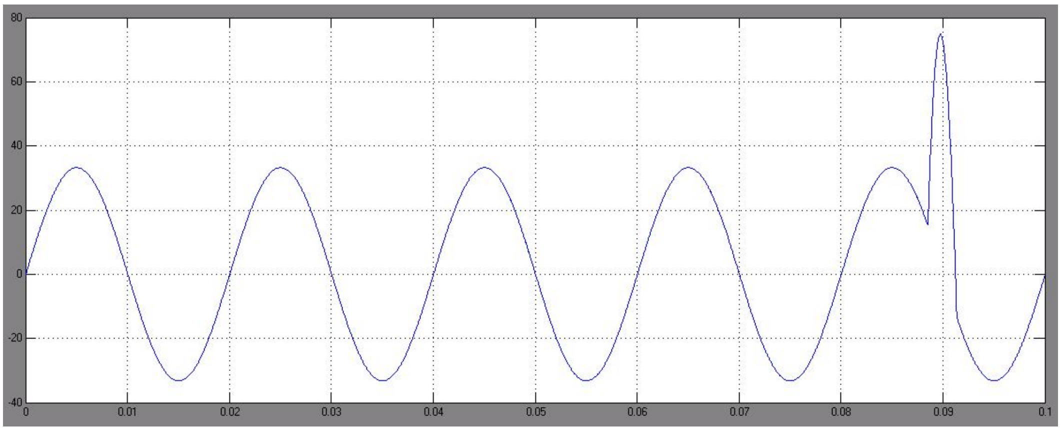

Figure 8: Simulation Output Current Waveform as seen by the Master (X-axis: time in seconds, Y-axis: current in Amperes)

B. Verification of Adequacy of Baud Rate

The proposed technology 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 Hz or60 Hz, the number of voltage zero crossings per second is 100 or 120.

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

Table 1: Actual Energy Consumption Details Provided by the Utility

S. No.	Area: Extn. - 1 Transformer Rating: 500 kVA Tariff Code Month: May-June 2012	No. 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	451 to 500	501 to 550	551 to 600	601 to 650	651 to 700	701 to 750	751 to 800	800 to 850	Total
1	LA1A-DOMESTIC	37	77	85	85	81	60	30	28	24	16	3	3	1	3	0	2	2	537
2	LC2A-PUBL LIGHT SUPPL-CORPORATION	1				2						2							5
3	LV2A-PUBL LIGHT SUPPL-VILLAGE PANCHAYAT																		
4	LM2C-ACTUAL PLACES OF PUBLIC WORSHIP																		
5	LM3B-INDUSTRIES -METRO																		
6	LN3B-INDUSTRIES-NON METRO			1										1				1	3
7	LM51-COMMERCIAL	35	10	5	4				1										55
	Total Consumers																		600

For the supply frequency of 50 Hz, assuming that the individual energy meters are designated addresses from 1 to 600, to complete one cycle of bi-monthly readings for the raw data given in Table 1, based on calculations done, it will take 53 minutes. If readings are to be taken every day for daily consumption, lesser time will be required to read all the meters, since daily consumption figures will be lower. However, this calculation does not take into account any coding scheme or majority-voting method that will be required to ensure integrity of data.This calculation was done to demonstrate that with this technology, it is possible to read all the meters connected to a typical distribution transformer, at least once a day.

Conclusion

This paper has presented a novel technique for power line based communications and has proposed the application of this technique for automated meter reading. Since this technique does not depend on modulation for data communication, no PLC modems are required. Today in any PLC based communications system, the cost of the PLC modem is significant. Hence the proposed system is a low-cost alternative to the existing PLC based AMR systems. Though the data rate will be lower when compared with the existing systems, it has been verified that this system meets the data rate requirement for the intended application satisfactorily. The use of power line signaling will introduce a limited quantity of voltage and current distortions. However, since these deliberate distortions are sporadic in nature, it will not significantly contribute to the total harmonic distortion of the distribution system. The next step is to implement the proposed technology on a LV distribution system and study its performance, in terms of adequacy of data rate, and influence on power quality if any.

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