Design of a STS Electrical Energy Meter with Two-Way Communications Capability over GSM Network

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Abstract. A STS (System Transfer Specification) energy meter with an embedded solution for two-way communications over Global System for Mobile Communications (GSM), was designed and simulated with Proteus. This meter should be able to report any tampering attempt on the customer’s meter, by sending an SMS (Short Message Service) via Global System for Mobile Communications (GSM) as regards energy theft from the point of theft to an automated meter management station. Every meter is part of an automated metering management network, which is a scaled down version of a conventional Advanced Metering Infrastructure (AMI). This research provides an additional capability to STS energy Meters. The additional two-way communications capability of the Energy Meter is implemented with the addition of a GSM module to a conventional STS meter. The additional functionality to the STS meter real-time reporting was achieved by adding a GSM module to its design.

Keywords: Smart Energy Meter, PIC micro-controller, Energy Theft, Advanced Metering Infrastructure, System Transfer Specification.

1. Introduction

This research work is aimed at the design of a System Transfer Specification (STS) meter with added two-way communications functionality a cost effective and lower version Advanced Metering Infrastructure (AMI) electrical energy meter with theft and energy consumption reporting capability. The meter should be able to report any tampering on the customer’s meter, as such, distribution companies will have a real-time report as regards energy theft from the point of the act. Since the meter is a constituent of an automated metering management network, reporting/communication to a center is very possible using Short Message System (SMS) via a Global System for Mobile Communication (GSM) network.

The smart meters deployed in Nigeria are of STS capability, and are limited to one-way communication; however, in a very short distance, two-way communications between the meter and its configured Customer User Interface is achievable, this limitation makes the meters venerable to energy theft because the DISCO is unaware of the theft. This research work has made it possible to get real-time report in the cheapest possible implementation.

Since the idea is to have a two-way communication between the automated metering management system and the off-takers meter, the convention is to deploy AMI meters. The AMI is the deployment of a metering solution with two-way communications to the electric meter [1],[15]. Such implementation will be more expensive, as such, the implementation of this research work will reduce the urge cost of implementing an Advanced Metering Infrastructure. This has a two-fold benefit to the Off-taker and the DISCO: in that, there will be no need for the off-taker to purchase AMI capable energy meters but STS meters, while the DISCO will be saved from the huge cost of setting up and maintaining AMI infrastructure.

The design is made-up of PIC18F45K22 microcontroller an IC from Microchip Inc. This microcontroller can be programmed to calculate numerous electrical power quantities...
parameters) such as; active energy, reactive energy, apparent energy, instantaneous voltage/current, power factor and line frequency. The single IC will take care of numerous electrical metering circuitry requirements such as analogue-to-digital conversion and signal processing. It processes the outputs of the current and potential transformers which are the basic analogue hardware that will have contact to the live and neutral wires of the main power supply.

Microcontrollers are basically narrowed down versions of earlier computers having a single purpose processor as against the multi-purpose processor of computers. It has so much capability and reliability though with limited computational power as compared with computers (PC) making it a good hardware candidate for this work. Its capabilities; computational power, in-built peripherals, size, and reliability are utilized in manipulating the outputs of the major analog components (current and potential transformers) in producing human readable information on a connected liquid crystal display (LCD) which is the consumed electrical energy of a customer [2],[14].

The tech-space is flooded with a variety of Application Specific Integration Circuit ICs that have features that track multiple layers of tampering of a metering system. In a standalone meter, with long distance communications, a tampering event can be stored in the memory to be reported during the meter’s monthly polling. The value of tamper detection increases tremendously if the meter is part of an automatic metering management network, where the event can be reported quickly and appropriate action taken to investigate and correct the condition [5].

2. Materials and Methods

The design of a smart energy meter using PIC18F45K22 microcontroller with reporting capability makes it a lower version of an AMI (advanced Metering Infrastructure) meter: the meter is able to report theft activity on real-time since the meter will be part of an automatic metering network. The design was implemented with simulation software, which emulates metering and anti-theft reporting using the various modules of the simulation software (Proteus).

The report function utilizes one of the capabilities of a microcontroller that causes an interrupt on its special PORTB pins when it senses a specified type of change, this change is tied to the state of the micro switches on the chassis of the smart meter. A tamper on any of the case screws will cause a change of state on the micro switch, this change is captured on the interrupt pins of the microcontroller and invokes the lines of code in software that deal with tampering. When the life and neutral wires are on power, the tampering detection is solemnly monitored by the interrupt feature of PORTB pins of the microcontroller.

2.1 PIC18F45K22 Microcontroller

The PIC18F45K22 microcontroller is a product of Microchip, it is a member of the PIC18 family of microcontrollers. This family offers advantages to all PIC18 microcontrollers namely; high computational performance at an economical price – with the addition of high-endurance, Flash program memory. On top of these features, the PIC18 (L) F2X/4XK22 family introduces design enhancements that make these microcontrollers a logical choice for much higher performance, power sensitive applications [3].
The choice of this microcontroller is tied to the following:

- EEPROM (Electrically Erasable Programmable Read Only Memory) which can be used in storing useful information.
- The PORTB interrupts that will work with the state of the micro switches for tampering detection. This interrupt module is also used in setting up high and low priority interrupts and subtasks in software.
- Enhanced Universal Synchronous Asynchronous Receiver And Transmitter module (EUSART) that was used in conjunction with an on-board GSM (Global System For Mobilization) module for reporting energy theft to a dedicated phone number over GSM network.

2.2 The GSM Module

GSM Click is a product of Mikro-Electronika, it is a perfect solution for adding GSM/GPRS communication layer to a project. It features Telit GL865-QUAD quad-band (850/900/1800/1900 MHz) GSM/GPRS module. The board contains a TXB0106 6-bit bidirectional voltage-level translator as well as a SIM card socket. GSM Click communicates with the target microcontroller via seven mikroBUS™ lines (RX, TX, INT, PWM, CS, RST and AN). GSM click can use either 3.3V or 5V power supply [4]. The module has worldwide coverage quad-band frequency (850/900/1800/1900 MHz), it supports incoming and outgoing voice calls, short message service (SMS) and data communications (via GPRS). The 900 MHz and 1900 MHz frequencies are used in most parts of the world (Europe, Africa, Middle east, Asia) while the 850 MHz and 1800MHz frequencies find use in North, South and central America. [4]. The designed energy meter utilizes its SMS sending functionality in reporting energy theft to a dedicated phone number that is part of the automatic metering management network saddled with the responsibility of responding to reports in real-time.

2.3 Proteus Design Suite

Proteus was developed in Yorkshire, England by Lab Center Electronics LTD. It’s a proprietary software tool suite used primarily by electronic engineers for electronic design automation. [10]. The Proteus simulation software in use provides a unique Integrated Development Environment (IDE) for testing and debugging without hardware as the software is equipped with a rich library of electronic components/devices to suit the design by simply having the right specification for each component in use.

The design utilizes Proteus schematic capture and simulation modules. The schematics capture comprised of the analog devices used with the microcontroller, each device and microcontroller properly configured to the specifications of the design, setting the base for the design phase of a PCB (printed circuit board) layout.

The microcontroller simulation is achieved by uploading an HEX file of the written software unto the microcontroller in the Proteus IDE, when this is successfully applied to the earlier, it is then co-simulated with the other analog (potential and current transformers, rectifier) and digital devices connected to it.
2.4. Current Transformer

A current transformer is a type of transformer used in measuring AC (alternating current) current; it produces current at its secondary terminal that is proportional to that at its primary terminal [11]. Like any transformer, a current transformer has a primary winding, a core and a secondary winding, although some transformers, including current transformers, use an air core. In principle, the only difference between a current transformer and a voltage transformer (normal type) is that the former is fed with a “constant” current while the latter is fed with a “constant” voltage, where “constant has the strict circuit theory meaning [11].

A current transformer is also referred to as an instrument transformer as it basically transforms high current on its primary winding to a proportional low current value that can be easily processed and then applied to control devices like a relay and digital/logic devices. For example, microcontroller utilized in measuring applications such as energy meters.

A current transformer has more turns of wire on its secondary winding while a turn or two on its primary winding making it apparently a step up transformer looking at it from the voltage perspective but from the current perspective, it is tempting to call it a step down transformer.

\[
\frac{N_s}{N_p} = \frac{V_s}{V_p} = \frac{I_p}{I_s}
\]  

(1)

Where \(N_s\) and \(N_p\) are number of turns in secondary and primary windings respectively and \(I_p\) and \(I_s\) are current in primary and secondary windings respectively.

From the fact that the secondary winding of a current transformer has more turns.

Equation(1) shows that \(N_s\) is inversely proportional to \(I_s\) and \(N_p\) is also inversely proportional to \(I_p\), it is seen that current transformers are step up transformers. Thus to differentiate them from other transformers, they are specified by the current ratio between their primary to secondary winding [14].

The standard current rating at primary winding for current transformers is usually 1-5A [13].

Accurate current transformers need close coupling between the primary and secondary winding to ensure that the secondary current is proportional to the primary current over a wide current range [11].

This research work utilize a current transformer configured to 100:1A current ratio in the schematic module of the Proteus simulator.

2.5. Potential Transformer

The potential transformer steps up or steps down voltage level. Potential transformers (PT), also called voltage transformers (VT), are a parallel connected type of instrument transformer. They are designed to present negligible load to the supply being measured and have an accurate voltage ratio and phase relationship to enable accurate secondary connected metering [12]. The voltage at the secondary winding of a potential transformer can also be easily processed to suit control devices like relays and logic/digital devices like microcontroller.

From equation(1), the number of turns on any side of the transformer is directly proportional to the voltage on its respective windings, thus, a potential transformer could be a step down or a step up transformer depending on the number of turns on the respective windings.

This design used a step down transformer rated at 220:12V, the secondary voltage when varied will give a proportional voltage at the primary winding which will be further processed and utilized by the metering electronics [14].
2.6. Micro-switch

The micro-switch is the component that is unknowably engaged during an energy theft operation (Tampering); here, it is connected to the microcontroller analog (AN9) input/output pin36. The switch has two basic states of ON and OFF which are easily tied to the digital states of 1 and 0 respectively: a change in state of the switch occurs when the seal on the meter chassis is opened or when the conduit housing the service cable is forcefully opened by anybody.

3. Simulation and Results

Every measurement system is designed to take on specific inputs, process them and give a proportional value of the input as output in a specific format. This research work takes as input the voltage across a potential transformer and the current through a current transformer. These are processed (rectified, smoothened) and narrowed down to proportional values that are easily manipulated for a microprocessor-based application. Subsequently, the consumed energy is calculated in software and displayed on a LCD [14].

As shown in Fig.2 when a theft attempt is made, the corresponding micro-switch connected to the multipurpose pin (36) of the microcontroller via a pull-up resistor will be activated and sends an analog signal to the microcontroller: the controller will then use its Analog function (AN9) to receive this signal. The digital oscilloscope as seen in Fig. 2 captures the pulse train of this SMS.

As also shown on Fig.3 after the microcontroller receives the analog signal on pin36, control in software is directed to the routine containing the default energy theft report SMS to be sent using the Transmission output (TX1) function of the USART pin (25). This SMS is sent to a dedicated phone number for the automated metering management centre. These centres can be spread across a DISCOs franchise area such that they can be carefully managed and staffed with information sharing.
Fig. 1 shows a design of an Automatic Metering Management network.

Fig. 2 shows the TAMPER (micro-switch) connected to the ANALOG INPUT(AN9) pin36 of the microcontroller via a pull-up resistor.

Fig. 3. Red arrow points a digital oscilloscope displaying the SMS being sent as digital signal from the USART PORT pin 25 RC6/TX. Green arrow shows the USART PORT pin 25 RC6/TX of microcontroller connected to the digital oscilloscope, Blue arrow shows the tamper detection message updated on the LCD.
Measurements needed

- Current through the customer’s load.
- Voltage across the customer’s load.
- Active Power measurement.

Current measurement
The specification of the current transformer in use is in the ratio [100:1] A, this will provide 1A of current at its output if the load through the input consumes 100A and will have 0.5A on the primary side if the load pulls current of 50A. From this it is shown that the multiplier is 100.

Since PIC micro-controllers take dc voltage between 1-5V as input and not current: therefore, the output of the current transformer which is a lower proportional value of the current through the consumers load needs to be converted to a proportional current value within 1-5A.

Through computational algorithm in software the exact value of current through load at the primary terminal of the current transformer is calculated and saved as a variable in the software code for further computational use.

From simulation using a dc motor load, the ac voltage across the secondary windings is so small that its peak value is lesser than 5V, as such there is no need for rectification. Rectification is definitely needed in a hardware implementation, since, some loads may consume more current, thus, the ac voltage across the burden resistor may have a peak value which may be greater than 5V: this voltage will permanently damage the PIC micro-controller. This can be verified from from Ohms law.

\[ v = i \times z \]  \hspace{1cm} (2)

where \( z \) is the impedance of the load as most loads are inductive or capacitive.

\[ i = \frac{v_{\text{peak}}}{z} \]  \hspace{1cm} (3)

Also,

\[ V_{\text{rms}} = \frac{v_{\text{peak}}}{\sqrt{2}} \]  \hspace{1cm} (4)

Voltage measurement

A 220:12V voltage ratio specification is used for this work, it is obviously a step-down transformer. Now the voltage across the consumer’s load will have its proportional voltage level across the secondary windings of the voltage transformer; a voltage of 12V at the secondary terminal depicts a voltage of 220V across the primary terminal. Since the microcontroller requires at most 5V dc of input voltage there is need to further process the secondary winding voltage to meet the requirements of the microcontroller.

The processing starts by rectifying the ac voltage to dc using a bridge rectifier circuit comprised of four IN4001 diodes. after rectifying the ac voltage there are some ripples of ac component therefore a smoothing capacitor of 470uF is placed across the output of the rectified signal: with this a steady dc voltage free of ac component is available as shown in Fig.3 below with a value of 15.3V dc. Since this voltage cannot be directly feed into the microcontroller, a voltage divider circuit is provided which provides 3.06V across the 100K
resistor: in some applications a Zenner diode will do just fine. This is now the input voltage will be feed into the analogue port of the microcontroller. It should be noted that this voltage varies between $0 - 3.06\, \text{V}$.

![Schematic capture of the circuit](image)

Fig. 3. showing how the voltage at the secondary winding of the PT is processed to suitable scale for microcontroller application.

**Power measurement**

A smart energy meter just like every other energy meter measures the electrical power consumed by a load over time in a periodic manner except there is no load consuming power at that time. The unit of measurement is the KWH (Kilowatt hour). From this unit it is seen that the electrical energy is a product of two basic units: watts and time. Looking into the watts which is also a product of three units: voltage, current and power factor, there was success in getting the current and voltage into the microcontroller, and the need to assign a value for the power factor. In this paper, an assumed power factor of 0.9 was used. Now, the other unit of time is in hours which is equivalent to 60 minutes or 3600 seconds. If power consumed is not up to an hour, then measurement is in fractions of the basic unit of time hour.

Where active power consumed over time

$$p = i \ast v \ast t \ast \cos \theta$$  \hspace{1cm} (5)

Where, $\cos \theta$ is assumed to be 0.9, $i = \text{current}$ and $v = \text{voltage}$.

From Fig. 4 the consumed energy of the dc motor after 10 minutes (0.166667 hours) is 0.093KWH as displayed on the LCD (liquid crystal display).

From equation (5), substituting for values; $i = 0.07, v = 12, t = 0.166667$ and $pf = 0.9$, we have

Energy= 0.126KWH.

Percentage error in measurement was evaluated below.

$Tv = \text{True value and } Sv = \text{Simulation value}$
Thus, the error in measurement from the simulation is $26\%$. This variation is attributed to time delays: the time it takes the LCD to initialize and update information, the speed of PC, the assumption that the DC motor is purely resistive against the fact that it is a capacitive load and the assumed power factor of 0.9.

![Fig. 4. Simulation diagram showing the PIC18f45k22 microcontroller interfaced with other components.](image)

$$\frac{Tv - Sv}{Tv} \times 100\%$$  
$$\frac{0.126 - 0.093}{0.126} \times 100\% = 26\%$$  

### 4. Conclusion

The additional functionality to the STS meter: real-time reporting was achieved by adding a GSM module to its design, thus making it a two-way communication device as against its conventional one-way communication capability.

With this implementation, a cheaper and narrowed down AMI meter can be deployed thus saving DISCOs the huge financial and human capital resources needed to implement a full scale AMI network with its associated need for expensive AMI capable meters.

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