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The Smart Monitoring Unit

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Abstract: Electric energy has become an essential and inimitable part of our daily life. This need is expected to even double within the next 30 years worldwide. Pakistan currently faces an acute shortage of robust infrastructure in the power sector which has led to country wide blackouts for the past ten years. A reliable power source is possible when latest norms and methods are adopted. This paper explains the design, computational aspects, and implementation of an electrical meter which is a step towards integrating new concepts for tracking electricity usage in Pakistan. The proposed technique was simulated on Proteus and was extensively tested using inductive and real loads. The technique implemented provided 40 computations in 60 seconds and an output on a remote desktop terminal. The data obtained provided a real time access to the values being utilized by the load, enabling it to pinpoint changes in consumption by the load. It qualified to provide results which can lead to shedding of unnecessary load by the user which will eventually result in less strain on the national grid.

Keywords: digital metering technology, utility management, energy management, electricity metering systems, advanced metering systems

I. INTRODUCTION

With the passage of time, energy meters have out grown the traditional electromagnetic induction concepts and have moved on to become more efficient with the use of modern technology. The pace of adoption of technology in Pakistan has relatively been slow, its downside being that the reliability of the power source has decreased with time. Hence there is an urgent need for research to be carried out in the power and energy sector in order to revamp the nation's crippled power network. Currently, Lahore Electric Supply Corporation has integrated similar meters [1].

Presently, energy meters available are costly, bulky and their designs are close source. In this paper, an open source, low cost electrical meter is analyzed. The proposed meter is less bulky, possess faster computation rate and easily prone to changes according to its user's requirement. It is capable of calculating basic electrical parameters like the current, voltage, power factor and frequency. The existing meters available are still using binary LCDs in order to display the readings. With the usage of Raspberry Pi (R-Pi), the device was made capable to display the results to the consumer via internet on a remote desktop application. Furthermore, the with the capability to connect more than one users connected to the server, the Smart Monitoring Unit (SMU) gave an ease to connect multiple devices (smart phones and tablets) to keep the consumer updated at all times without the inclusion of any extra module.

II. OBEJECTIVES

The objectives of this paper are as follows;

1. To be able to simulate a resilient design capable of measuring electrical parameters on a distribution substation with accuracy and reliability; having a communication ability at a relatively low cost. All the simulations were carried out on Proteus simulation software. Simulations were performed at every step in order to ensure that the proposed algorithms produced the desired output.
2. To study, test and diagnose the increase in accuracy of the ACS 712 (Hall-effect sensor) to the design instead of current transformer (CT). The goal is to study the working and effective integration of off the shelf equipment such as operational amplifiers and diagnose the accuracy obtained for the extra effort expended in incorporating such sensors into the design of a metering unit.
3. Since the proposed technique allow measurement/diagnosis of power factor usage using the same module, to develop a complete framework for the analysis of inductive load.

The concept design is described in fig. 1

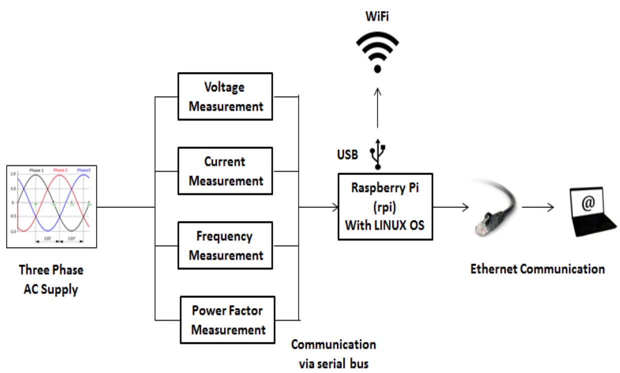

Fig. 1 Concept Design of the Smart Monitoring Unit

III. ANALYSIS OF THE METERING UNIT

The metering device was conceived in two parts which were later integrated to perform as one unit.

A. MEASUREMENT BLOCK

i. Frequency Measurement

The frequency computation methods initially available, adopted a technique which calculates the number of pulses which were digital inputs into the micro-controller. Through initial simulations it was identified that the problem in applying such method would cause a discrepancy in case of fault. It was further noted that in case of fault the pulse count would change within microseconds causing the method to fail. This posed a threat not only to the equipment but to the concerned personnel near the apparatus as well.

For proposing a new method for the computation of frequency calculation, the methods devised by Boualem Boashash were used. The papers [2] [3] discuss the properties and characteristics of stationery, non-stationery signals and the concept ‘Instantaneous Frequency’. The concept of instantaneous frequency which was adopted as a replacement for the previous one arises from the fact that non-stationery signals do not offer themselves properly to decomposition into sinusoidal components.

The main aim in applying the instantaneous frequency algorithm was to decompose the real world signal into its basic and fundamental components, the sine and cosine components. The method employed was mentioned in [3] where the input signal was turned into digital and turned locally stationery. The frequency was given by the inverse of the period, or alternatively by half the inverse of the interval crossing that is given by eqs. (1) and (2);

$$f=1/T_z \quad (1)$$

$$f=Z/2 \quad (2)$$

Where T, is the interval between zero crossings, 2T, is the period, f is the frequency, and Z is the zero-crossing rate. Since we were dealing with discrete-time signals with unit sampling rate, the value of T, is actually given by the number of sample intervals, k, between zero-crossings, and therefore the equation becomes eq. (3)

$$f=1/2k \quad (3)$$

(It was assumed for the present that the zero-crossings fall exactly on sample points). Then there will be exactly k + 1 sample points in the interval between consecutive zero-crossings (including the two end points). Fig. 2 shows the flow chart of frequency measurement.

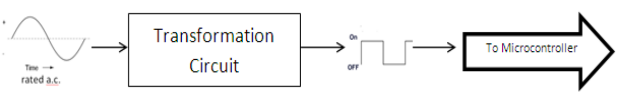

Fig. 2 Flow Chart of Voltage RMS Measurement

ii. RMS Measurement

The Root Mean Square (RMS) [4] value of an alternating quantity (voltage or current) is the value equivalent to DC value that will produce the same amount of heat to a fixed resistive load.

The current method usually employed in the RMS measurements uses average responding to instantaneous value which results in the quantity to be under measured. This is due to the fact that the practical loads do not form perfect sine waves. As a result, a certain factor needs to be multiplied with the output reading of the meter to obtain the actual result. The factor depends on the shape of the output waveform and hence the load.

It was proposed to use AD736 [5], a low cost, low power, true RMS to DC Converter that converts an AC voltage to DC value equal to same true RMS value as of converted AC wave. This converter is highly accurate and performs RMS conversion for crest factor up to 5 which is most suitable for practical loads, additionally this convertor has high input impedance (1012 Ω) so no external voltage buffer is required to counter loading effect.

Furthermore, a filtering capacitor was used to make a low pass filter for ripple removal in the output waveform. True RMS converters are smart rectifiers; they provide accurate reading regardless of the shape of waveform. The flow chart of voltage RMS measurement is shown in fig 3:

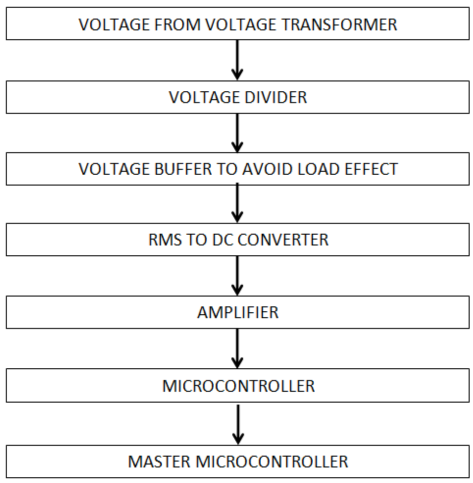

Fig. 3 Flow Chart of Voltage RMS Measurement

The voltage from voltage transformer was passed through voltage divider circuitry to step down, then it was passed through the voltage buffer to avoid loading effect, afterwards the sinusoid was passed through RMS to DC convertor. Finally, the output was amplified and applied at ADC of microcontroller where RMS value was calculated by multiplying it with scaling factor.

The current RMS measurement was calculated by passing the current from the current transformer through current sensor to convert in voltage equivalent wave, DC offset was removed using high pass filter which was passed through a buffer to avoid loading effect, and afterwards the sinusoid was passed through RMS to DC convertor. Finally, the output was amplified and applied at ADC of microcontroller where RMS value was calculated by multiplying it with scaling factor.

iii. Power Factor Measurement

Power Factor [6] is defined as the ratio of active power to apparent power; it is also defined as the cosine of phase angle between voltage and current waveform. Practically a good power factor shows that more power is utilized for useful work.

The voltage level was required to be scaled down to microcontroller level (5V) using the voltage divider circuitry. Afterwards, the low voltage sinusoid was passed through buffers to avoid loading effect i.e. the next stage will not act as load for previous stage, finally the low voltage sinusoid voltage wave was converted into rectangular wave and applied as input to exclusive OR (XOR) gate. The working flow of the power factor measurement is shown in fig. 4

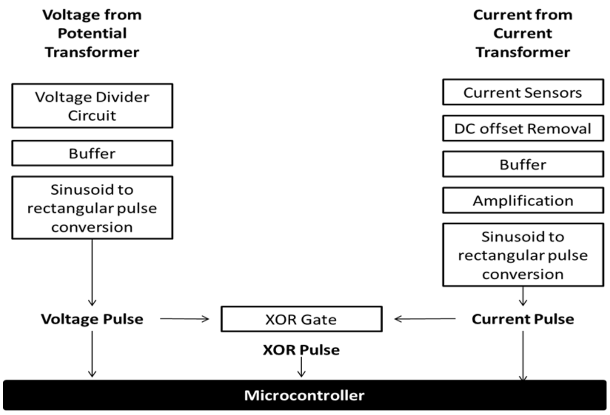

Fig. 4 Flow Chart of Power Factor Measurement

The high current was converted into a voltage equivalent sinusoid using a Hall Effect current sensor and since the current sensor gave a DC offset in the output, it was required to remove it by using high pass filter for further processing. The current sensors also had low sensitivity therefore it was passed through an amplifier. Finally, the sinusoid waveform was converted into rectangular pulse and applied to XOR gate as shown in fig. 5

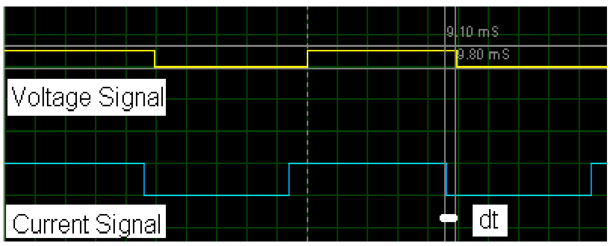

Fig. 5 XOR Gate Simulated Output

XOR output, voltage signal and current signal in pulse shape were applied at the digital input pins of microcontroller, the time "d_t" was measured which was the output of XOR gate, it was obtained because 2 inputs XOR gives high output when any one of its input is high. Finally, the power factor was calculated from the output of XOR gate using the timer function of microcontrollers. The leading and lagging power factor was determined by detecting the zero crossing of voltage pulse in the following manner:

Check Voltage pulse
If voltage = high
Check current pulse
If current = high
Current leads voltage by angle θ
Display + sign
Else
Current lags voltage by angle θ
Display – sign

The results were displayed on LCD connected to PIC microcontroller and the timer was reset after particular intervals for continuous power factor measurements.

iv. Communication Block

Power utility companies like to supervise data from a remote location. Keeping this at upmost priority SMU is designed to transmit data to any location at a faster rate of update without making any compromise on reliability of the system.

The data measured by the microcontroller was transmitted to a remote device. For this purpose, the data was forwarded to Raspberry Pi (R-Pi) which decreased the overall cost and increased the efficiency. The R-Pi was programmed to transmit data to the desired location using TCP/IP protocol. The benefit of using the TCP/IP protocol was that it provided good failure recovery, it had the ability to add networks without interrupting the existing services and most importantly gave us a platform independence. In order to increase the system security during communication, the system's reliability was increased by sending the data through wired medium i.e. Ethernet. The communication block of SMU is further divided into two parts:

i. Micro-controller to Raspberry Pi.
ii. Raspberry Pi to Web Server.

i. Microcontroller to Raspberry Pi

Microcontroller was connected to R-Pi through a UART (Universal Asynchronous Receiver/Transmitter) which was used in conjunction with communication standard RS-232. UART took the whole byte and transmitted the data sequentially. At the receiving end another UART assembled the incoming bits into bytes. Another reason to prefer serial transmission was its cost effectiveness over the parallel transmission as it required a single channel over the transmission. The transmission of data was in binary form. The fields occupied by a single phase voltage was calculated to be 7 bytes including the unit. For three phase voltage, the occupied fields became 21. Likewise, power factor and current occupied 21 fields, frequency occupied 6 fields. Summing up all the bits, including the starting, ending and status bits, approximately 74 bytes were transmitted in a single frame. Whereas the standard baud rate is 9600 bps. For UART TX the byte requirement was around 9 to 10 bits. Hence, the total number of bits transmitted in a single frame became 740 bits. In this way approximately 13 frames were transmitted in a second which was much higher as compared to other systems which are currently employed. The transmission of the message sequence is given in table 1:

#	#	V_1	V_2	V_3	U_V	I_1	I_2	I_3
PF_1	PF_2	PF_3	FREQ	SB_1	SB_2	SB_3	SB_4	@

Table. 1 Data Sequence of the Message Signal

Where,
‘#’ indicates the new frame has just started.
‘V_1’, ‘V_2’, ‘V_3’ indicates the voltages of 1st, 2nd and 3rd phase respectively
‘I_1’, ‘I_2’, ‘I_3’ indicates the currents of 1st, 2nd and 3rd phase respectively
‘PF_1’, ‘PF_2’, ‘PF_3’ indicates the power factor of 1st, 2nd and 3rd phase respectively
‘FREQ’ indicates the frequency of three phase system
@ indicates the ending of character frame
SB_1, SB_2, SB_3, SB_4 indicates the status bits

ii. Raspberry pi to web server

The transmitted data, now available at R-Pi analyzed the bit stream by multiplying the bit stream with ‘FH’ i.e. all ones, this multiplication process was done by using ‘AND’ gate and the phenomenon is known as “parsing”. TCP/IP (Transmission Control Protocol/Internet Protocol) was the fundamental protocol. It was set up with direct access to the Internet, the user’s computer provided with a copy of the TCP/IP program just like any other computer that may send messages to fetch information from TCP/IP. The program flow of the communication is shown in fig. 6

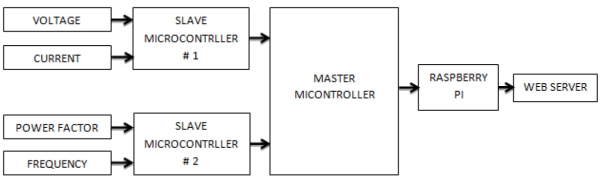

Fig. 6 Communication Flow

IV. RESULTS

The circuitry consisting of analog and components were designed for measuring power factor, frequency, current and voltage of a load connected. The current and voltage signals of the load taken from output of the zero crossing detectors. The signals were checked and verified on a simulator, terminal display and on an oscilloscope. The table 2 compares the results observed by SMU and other measuring devices. All the parameters in the table 2 are that of a residential load.

Parameters	Measurements through Analogue Meter	Measurements through Oscilloscope	Measurements through SMU
Current (RMS)	4.749 Amp	N/A	4.75 Amp
Voltage (RMS)	164.99 Volts	164.98 Volts	164.97 Volts
Frequency	N/A	50.02 Hz	49.98 Hz
Power Factor	N/A	0.846 Lagging	0.85 Lagging

Table. 2 Results

The output of frequency and power factor as seen in the terminal device is shown in fig. 7.

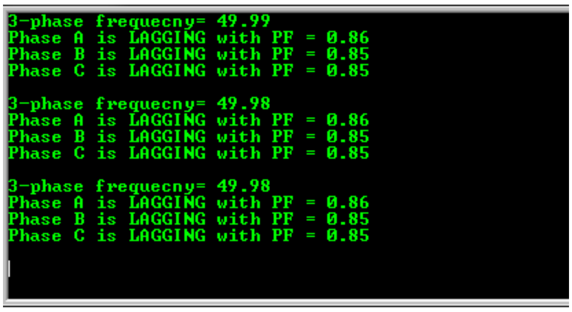

Fig. 7 Frequency and Power Factor Combined Output

The outputs of voltage and current on an oscilloscope are shown in Fig. 8

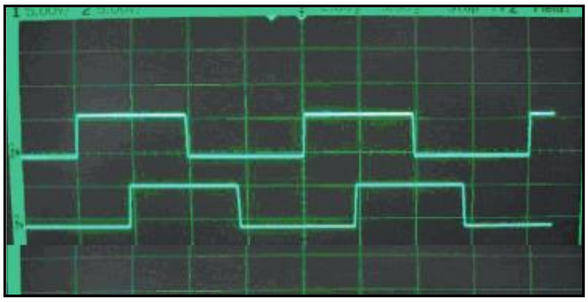

Fig. 8 Voltage and Current Waveforms

V. CONCLUSION

The technology regarding electric metering is evolving and research is being carried out to facilitate the user. The Smart Monitoring Unit (SMU) project intended to enhance the operational flexibility of existing electrical power meters. The following project was a small step to introduce new norms and practices in the power systems of Pakistan. Its aim was to assess if off-the-shelf equipment, faster signal processing algorithms and an effective wired internet communication would result in a robust device. Off-the-shelf equipment, faster signal processing algorithms and an effective wired internet communication resulted in a robust device. It was desired to provide cost-effective solutions for operational needs which was achieved by using op-amp based circuits. Though a prototype the milestone of better and fast algorithms was not only simulated but tested as well.

VI. FUTURE PROSPECTS

With technology evolving at eye blinking speed, the Smart Monitoring Unit holds huge growth prospects in the future years to come. Owing to the open ended design, the SMU can be programmed and functioned according to the needs of the users. The inclusion of Raspberry Pi further helps in integrating existing and new protocols followed that might be followed by an industry.

Firstly, the device can be worked upon to make it artificial intelligent. The SMU can be aid in load monitoring where the device will be installed to the mains of the zone to be monitored because there is a pattern in the usage of electricity. The SMU will be intelligent enough to predict usage patterns and suggest recommendations on how to switch loads and manage loads in order to achieve maximum possible cost saving. The concepts shared in 'Non-Intrusive Load Monitoring' theory as well.

Secondly, for very long distances and to achieve long distance communications there is a possibility to add a Wi-Fi dongle to the Raspberry Pi and make it wirelessly enabled for internet communications. The system currently can be made to make a Wide Area Network (WAN). The current system can cater to only a grid and a small area. With WANs the electric companies will be able to save huge costs which are a burden for the existing system. They will enable the operators to detect the faults and pinpoint the location quickly and efficiently. This will result in increasing the reliability of the system.

Lastly, the system can be adjusted to empower home users and industrial users alike, giving an ease towards load management.

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Fig. 5 Voltage and Current Output

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