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Design Multi-Channels Energy Meter for Demand Side management

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ABSTRACT
This paper presents a design for a low-cost smart meter. It is designed not only to measure the consumers' energy consumptions but also to monitor, operate and control the loads. The introduced smart meter is linked with a desktop personal computer using Arduino-Uno kit and simulation software called LabVIEW. The meter displays voltages, currents, power consumptions and energies in and out with its related cost. In the proposed meter, the home loads are connected in groups and each group is connected to the meter via channel based on their essentiality and criticality. Depending on the status of the distribution grid, the operator can control the domestic application by switching on or off each group or channel via meter. The proposed meter also can automatically switch off power to non-essential channel when the total power consumed exceeds the limits in the meter setting. Social justice is guaranteed by this action as the energy is not completely turned off in a zone and not the others at emergencies. Results obtained from the designed meter shows fair amount of accuracy for measuring a number of different loads which proves the validity of the meter.

***Keywords* -** Smart Meter (SM), Arduino UNO microcontroller, LabVIEW, Virtual Instrument (VI), Demand Side Management (DSM)

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I. INTRODUCTION

Demand Side management (DSM) can be defined as a program applied by distribution companies to manage and control the power flows and energy consumptions at the customers sides of the energy meter [1]. This program is used to maximize the utilizations of the available energy without the need to increase the capacity of the generated and transmitted power. DSM program can be energy efficiency program, energy conservation program, demand response program, and load managements program [2]. Reducing and shifting the consumptions are the main objectives of the domestic load management and control program [2, 3]. These objectives can be accomplished at customers sides by emboldening energy conservation patterns and constructing smart energy buildings. However, actual solutions to control the home powered appliances are needed to decrease peak load demands.

Conventional energy meters had been used since the previous century. These energy meters could be installed in the electric system to arrange the data sharing between the devices in energy generation and consumptions. There are two types of the conventional energy meter; single and three phase energy meters. Most of conventional energy meter was based on the induction theory and called electromechanical meter. It consisted of a rotating cup fabricated from aluminum material linked to a clock and gear mechanisms that used to display the energy consumptions [4].

Recently, meters become digital but they still have some disadvantages. Many distribution systems had started to install the digital smart meters instead of the conventional meters by mass deployment [5, 6]. The main disadvantages of the conventional energy meters are; the manual process of meter readings, monthly pay of electric bill, complicated structure and software and insufficient communication method [7].

Digital energy meter with description such as input circuits (voltages and currents sensors and amplifiers), output circuits (16x2 character LCD), and processing circuit (ATMega8 Microcontroller) was proposed in [8]. A residential load management scheme of an energy meter to control the domestic devices was presented in [9]. It supported the frequency response by using the measuring frequency to activate the load block signal for the smart meter. Ref. [10] presented an algorithm for data acquisition and analysis for smart digital meter. Moreover, the smart energy meters benefits for the new cities were illustrated. The integrated circuits were implemented to determine the power consumptions in [11]. It used the power line carriers and radio frequency as communication methods.

Ref. [12], proposed an energy meter for measuring the power and managing the power quality. This meter is associated with Wi-Fi communication kit, software and hardware systems. Ref. [13], presented an energy meter for tracking the customers consumptions by an optocoupler sensors. It detected the produced LED optical pulse by using microcontroller to calculate the energy. Ref. [14], used the electrical power cables to transfer the data of the automatic meter reading devices. Ref. [15], implemented a smart meter which can be easily installed to measure the electrical power. The smart phone was used to transmit the energy data. Smart energy meters had been proposed for different applications such as measure energy consumption, discover energy theft, remote control the supply of power, variable pricing over time, detect electric faults and monitor the quality of power supply [16, 17]. Smart energy meters are presented in electric grids over the world to provide the electric companies and consumers with the complete real time data about the consumed power and pricing information. Based on this information, the customers are expected to decrease the energy consumption. These smart meters enjoy with; low operation cost, simple in metering, on line bill payments and automatic control the loads. However, the main disadvantage is that, it cannot measure the energy and power of the individual devices. Ref. [18] introduced a smart meter based on the IoT using the Arduino Uno Kit and current sensors to measure the individual devices power and transmit it by the internet. But the system is complex to implement. From the previous literature survey, it is required to present an energy meter which can control and measure the individual devices consumptions. Also, this meter can be installed easily in the existing system.

This paper proposes a new design for smart meter that monitor the voltages, currents, and consumed energy by domestic appliances with a simpler sensing circuit. The designed watt meter consists of four main parts; input circuit, signal conditioning circuit, processing and control circuit and output or display. Input circuits consist of voltages and currents sensors to get the voltage and current waveforms. Signal conditioning circuit to handle voltage and current waveforms to the processing unit in such a form that can get it. Processing and control circuit consists of an Arduino micro-controller chip to perform mathematical calculation to get power and energy consumption. The Processing circuit using Arduino micro-controller that has been connected with Universal Serial Bus (USB) power supply. USB power supply of the microcontroller was used as the power supply of the meter circuit. The Arduino microcontroller that has great advantages which are: cheap, reliable, open source, easy programming and easy to connect with PC. Measurements of voltages, currents, power, and energy consumptions are simulated using LabVIEW program.

II. METERING THEORY AND FUTURES

The proposed meter uses the voltage dividers rule for the voltage's sensors. However, the current's sensors apply Ohm's law to transform the currents values to voltages values. The measured voltage and current signals for system are tuned to be compatible with the Arduino. The analog signal is converted to digital by the Arduino kit. After that, the digital signal is transmitted to the computer for processing and calculating the required information. The required information can be graph of voltages, currents and energy consumptions. In addition, the values of the Root Mean Square (RMS) and the average can be illustrated by the program.

Voltage divider is a circuit that splits the input voltage into two specific voltages. It can be constructed by combining two or more impedances in series. In this paper, the voltage divider is constructed by connected two resistors.

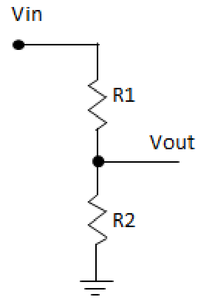

Fig. 1 Circuit of voltage divider

$$V_{out} = \frac{R_2}{R_1+R_2} V_{in} \quad (1)$$

Electric power is defined as the rate of expending energy and the unit for measuring power is watt (joule per second (J/s)). Power is converted into other forms of energy when the electric charges move through the difference in potentials between two points which occurs in electrical components in electric circuits.

$$P = I * V \quad (2)$$

where *V* and *I* are the electric voltage and current. Energy is defined as the ability to do work and the amount of energy consumed (or supplied) depends on the power and the time for which it is used.

$$E = P * t \quad (3)$$

where *E* is energy in watt hrs, *P* is power in watts and *t* is time taken in hour.

III. VOLTAGE MEASUREMENT

The main objective of the electronic conditioning voltage signal as illustrated in Fig. 3 is to adjust the output voltage of the Potential Transformer (PT) that to be suitable to the Arduino inputs. Where it is required positive voltage from 0 to 5V. The PT output voltage signal is very closed to sinusoidal waveform. This PT output voltage is proportional with the AC input voltages. The electronic conditioning voltage signal circuit converts the output voltage of the PT to a sinusoidal voltage waveform with positive peak value lower than 5V and negative peak value greater than 0V. So, it adds an offset value to remove the negative value from the voltage waveform and tuned down the positive values.

The voltage divider circuit is used to scale down voltage waveform. It is linked with the terminals of the adapters. While the offset value is added by implementing a power supply formed by another voltage divider circuit linked to the power supply of the Arduino. The Arduino needs only positive voltage values, so by connecting the terminals of the PT to ground (0V) and 2.5 V level, the voltage signal will be oscillated around 2.5 V and still positive.

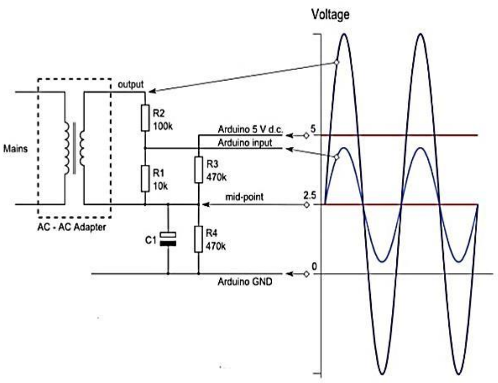

Fig. 3 Conditioning voltage signal to fit Arduino input

IV. CURRENT MEASUREMENT

To connect the current transformer sensors to the Arduino Kit, the output current signals from the current transformer sensors need to be adjusted. So, current signals meet the Arduino Kit analog inputs requirements, where it needs voltage values in range between 0V and 5V. This can be satisfied by the circuit illustrated in Fig. 4 that contains two main parts; current transformer sensor and resistors (burden and voltage divider resistors (R_5 and R_6)).

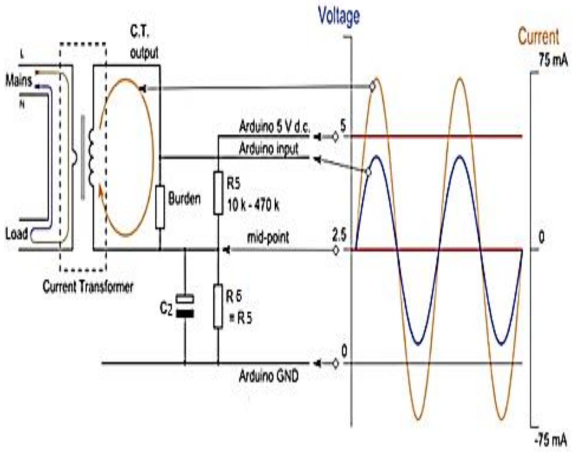

Fig. 4 Conditioning current signal to fit Arduino input

The current signals need to be transformed to a voltage signals with burden resistor. By connecting one terminal of the current transformer to ground (0V) and obtain the voltage value from the second terminal attributable to the ground, the voltage value will be oscillated between negative and positive voltage values. The Arduino Kits require only positive voltages and so by connecting the terminals of the current transformer to ground (0V) and 2.5 V level, the voltage signal will be oscillated around 2.5 V and still positive.

Resistors R_5 and R_6 in the circuit shown in Fig. 4 make up the voltage divider circuit that achieves this 2.5 V level. The capacitor C_2 has low reactance value to provide low impedance for the AC current path, effectively bypassing the resistor. To choose the suitable values for the resistors R_5 and R_6, it is preferred to be high resistance as it consumed low energy.

V. PROPOSED ARCHITECTURE OF POWER METER

The smartness of the proposed meter conceals in the ability to control the power supply to the loads besides measuring and displaying the energy consumed and its cost. There are two methods to control the loads; the first is automatic shedding when the customer exceeds his predefined power consumption and the second is manual shedding by operator as he can turn off some or all meter channels when the power system is in danger.

5.1 Software design

The digital data is processed and mathematical operations are executed using labVIEW program. LabVIEW software is created by the National Instrument (NI) Corporation to model, design and simulate the instrument systems by using visual programming language. Moreover, the

LabVIEW could be called Virtual Instrument. Each Virtual Instrument is consisted of three main components, front panel, connection panel and block diagram. The construction of the designed program is illustrated on the block diagram panel. While, the front panel is used to present the designed program results, and the connection panel is used to display the virtual instruments [8]. Some advantages of LabVIEW which are [21]:

- The compact user interface components do not require exactly any programming. The components are placed directly on the front panel then the terminal data appeared on the block diagram.
- There are too many drivers for data acquisition and testing devices.
- Process multi-tasks for data acquisition and control in the same time automatically.

After the data was converted from analogue to digital, the LabVIEW program processes the digital data. Then the currents, voltages, power and consumed energy are presented in the numerical and graphical forms. The instantaneous value of energy is calculated by multiplying the power signal by the time duration of the analogue digital converter.

5.2 Hardware design

In this study, the power supply of the applied microcontroller generates a fixed output voltage of 5V. Then it is used to transform the sensors outputs voltages to reach a value that the Arduino Kit can examine properly. Here is a picture of the Arduino Uno that is used [19].

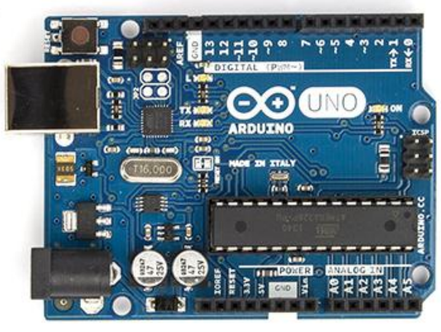

Fig. 2 Arduino UNO board

The hardware design of the proposed multi-channel energy meter is illustrated in Fig. 5. The power meter circuit has voltages and currents sensors. The voltage divider of R_1 and R_2 that exists on the voltage sensor are used to scale down the voltage signals from the PT. After that it is shifted by a value of 2.5V by using the resistors R_3 and R_4. For the current sensors' circuits, the voltages are achieved by multiply the secondary current of the current transformer and the burden resistance 15Ω. After that, the voltages signals output from the current sensors are offset by 2.5 V using R_5 and R_6. Therefore, the value of resistors; R_3, R_4, R_5 and R_6 are determined to be 470 kΩ as shown in Fig. 5. These resistors have been connected to 5 V power supply of the microcontroller, so that, the currents and voltages output signals have values from 0 to 5 V. Output voltage of 2.5 V refers to zero of current and voltage sensors, while 0 V and 5 V refer to minimum and maximum values, respectively.

The both signals, current and voltage, are ready to be read by the Arduino controller and connected onto the analog pins A0 and A1 respectively. The ON/OFF control of the load is done using a 5V DC relay which is capable of cutting off load up to 10 A [20]. The relay is controlled by signal from the Arduino digital output pins where low output (0V) means load is connected and high output (5V) means load is disconnected. Fig. 6 shows a real image of laboratory experiment of the proposed meter.

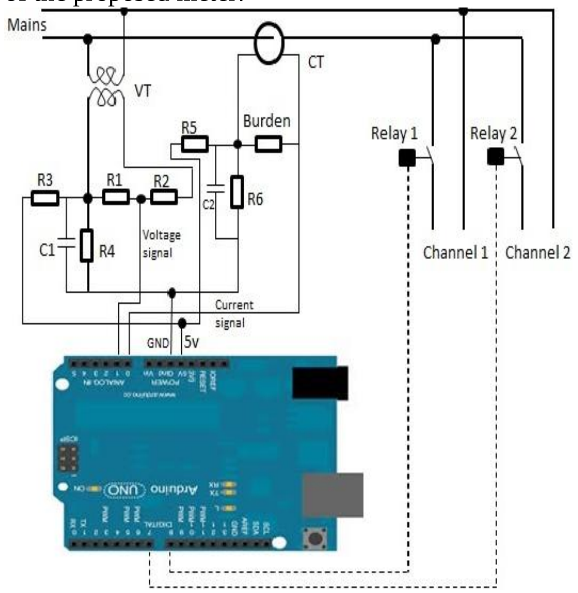

Fig. 5 Hardware combination of the proposed meter

VI. RESULTS AND DISCUSSION

In this paper, experiments have been executed to measure the power and consumed energy by two lamps with different power rating connected in parallel and each one represents a meter channel. Graphical user interface (GUI) is represented using front panel of the LabVIEW program that show graphs of voltages, currents, power, and consumed energy and show RMS values for voltages and currents, the average power values and the total value of energy consumed as shown in Fig. 7. The run time of the program and the cost of the energy consumed are also displayed. The meter is capable of disconnecting one or both load channels manually by the operator and/or automatic when the power reading exceeds a predefined value.

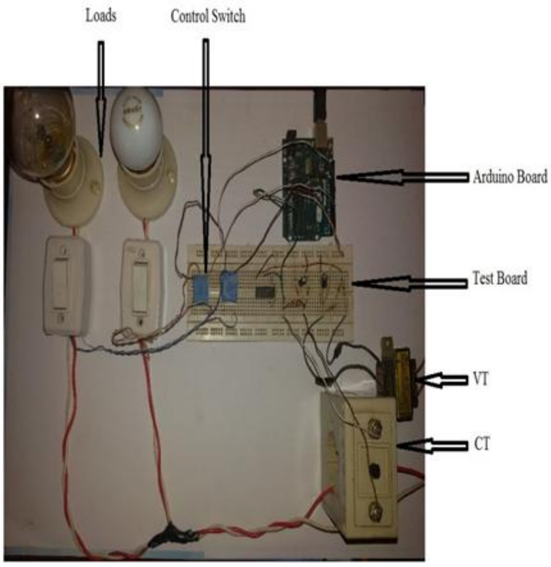

Fig. 6 Laboratory experiment

The power meters do not provide accurate results for the very low power consumed loads. This is because the limitations of current and voltage measurements settings. Maximum power that can be measured is depended on the maximum values of the measurable voltage and current. This is related to the limitations of the scaling methods of the used microcontroller and the resistors. Using this energy meter, a test is performed by measuring two lamps each one represents a load channel. The measurement results are illustrated in Fig. 7.

If the customer did not respond to the increased tariff by decreasing his consumption, then the proposed meter has two control actions. The first control action is automatic by switching off the non-essential load channel when the total energy consumed exceeds the limit that the meter is designed.

This action acts like as specific load shedding because the customer loads are not completely turned off while the essential loads are still served. Social justice is guaranteed by this action as the energy is not completely turned off in a zone and not the others. Fig. 8 explains the channel automatic power off when the energy exceeds the limit.

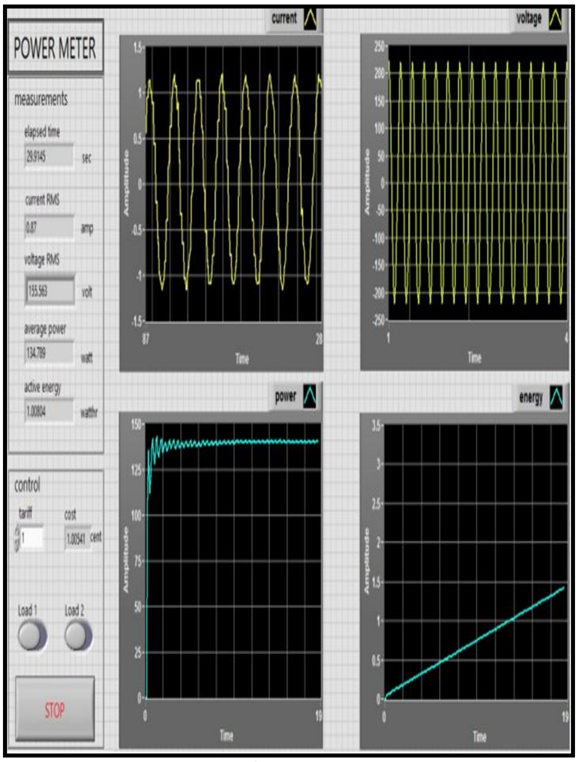

Fig. 7 GUI of the proposed meter

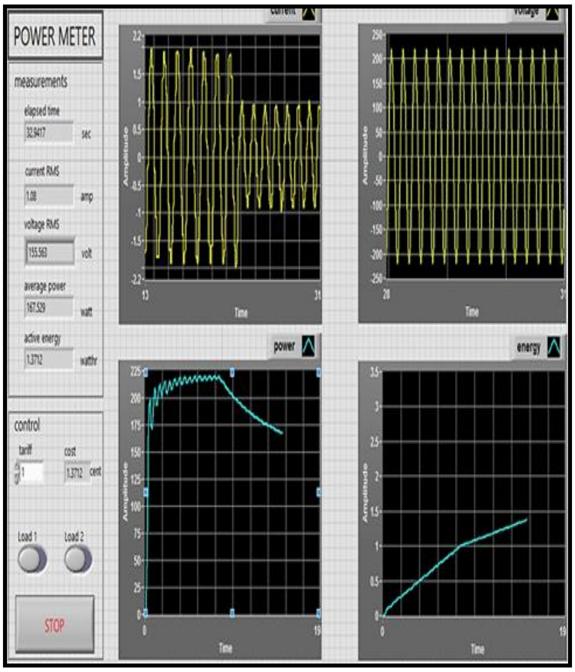

Fig. 8 Automatic channel power off when the energy exceeds the limit

Fig. 9 shows the second control action that is manually turning off the non-essential load channels by the operator. The more critical is the power grid, the more channels are turned off. This action makes the operator to act freedom with loads by turning it on or off depending on the power status.

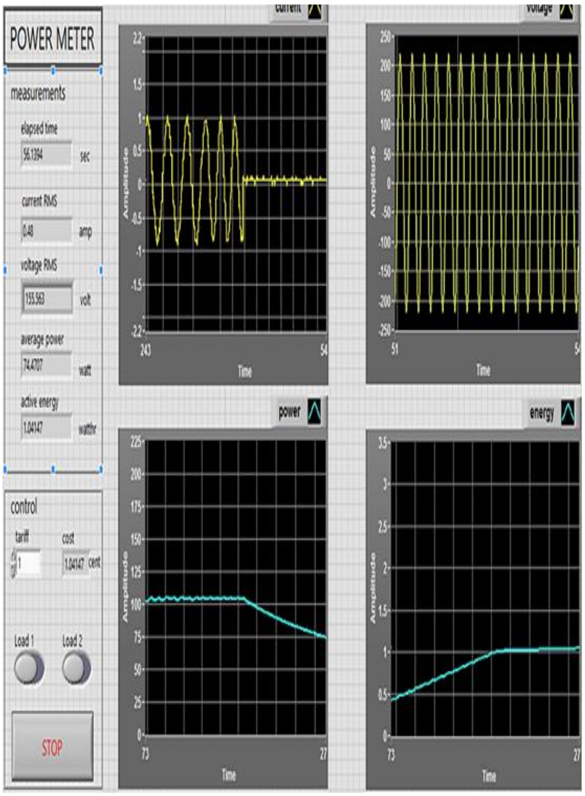

Fig. 9 Manual power off by operator at emergencies

VII. CONCLUSION

The proposed smart meter has two functions. First function is to measure the voltages, currents, power, and consumed energy and display them in graphs, RMS values and average values. Second it can control the domestic loads by disconnecting meter branches manually by the operator or automatically when consumed power exceeds a predefined value that can help with demand response programs.

The proposed smart meter has the following features:

1. Low material cost for the hardware and usage of open-source software that makes this meter is less expensive comparing with other meters.
2. Enables the possibility to use it as a source for numerous measurements of data like current, voltage, power and energy.
3. Simple design.
4. Flexible GUI to make sure the smart meter and its data are useable for several people, especially without a technical background.

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