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Enhancement of Single-Phase Energy Meter in Residential Area Using GSM Shield Sim9000 for An Economics and Environment Assessment

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Abstract

Enhanced energy or electrical meter is a new kind development on electricity measurement and energy consumption observation. This system will automatically send information to the energy supplier. The demand of energy consumption is increased because of the growth industrial development. Thus, the accurate energy bills are most important. Furthermore, the enhancement of this system is important for the supplier in case of excessive energy consume from the costumer. It can be seen that the number of consumptions for these past few years are increasing. Thus, the method of using prepaid energy meter system is one of development that give benefit to both consumer and supplier.it will give the consumer having sense about their energy consumption. the design of this project consists of Arduino, energy meter, GSM, mobile phone, voltage and current sensor, and relay. Each of this component have major important role for the prepaid energy meter. This project will also review on modelling Prepaid Single-phase Energy Meter using MATLAB/Simulink software. Where it is consist of voltage and current block, real power block, power factor block, energy measurement subsystem and recharged subsytem. This study presented the enhanced energy meter using prepaid method which give result to control the energy consumption. the result between simulation, prototype and calculated load shows the efficiency of the system.

Keywords: Energy Meter, Globla System for Mobile Communication, Energy Consumption, Single-phase System, MATLAB/Simulink

Introduction

Over the final century, power demand has increased exponentially and is a topic to energy issues today and the effort to resolve this issue is by reducing the usage of electricity in household or industry. Since 1891s, the electricity meter has been applied through a series of invention buildings. Electricity and energy meters are machines that calculate the amount of power used by households and electrically powered devices and store the consumer's past power usage (Omijeh & Ighalo, 2013). It will constantly measure the voltage and current readings to determine the amount of energy used or utilized over a specific period. By this, utilities can track the number of energy consumption through the grid for each of the units. The equipment can be classified into two different categories which are electromechanical and electronic. The most popular form of the energy meter is an electromechanical induction watt-hour meter. It works by counting the revolutions of a nonmagnetic, but the electrically conductive metal disc is set to revolve at a rate proportionate to the power going through the meter. The number of rotations is related to the amount of energy consumed. There are two types of energy meters: single-phase energy meters and three-phase energy meters (Raman, 2012). A Single-phase energy meter is commonly used in the residential area. Where it is only dealing with low-level voltage which is 240V. It can be seen every household in Malaysia was installed with an energy meter to keep track of the energy consumption where is also called a conventional energy meter. This type of energy meter has a certain downside. Until now, energy meters could only control and monitor the consumer's energy use (Bimenyimana & Asemota, 2018). In addition, the existing system is error-prone, requires a lot of effort, and takes a long time (Langhammer & Kays, 2012). several downsides of energy management where it effected to both company energy supplier and consumer from the residential(Peter & Iderus, 2021) thus, the needs of improvement energy meter are very critical to avoid excessive usage from consumer.

Many improvements in research and development, such as the SEM (Smart Energy Meter), have been developed. This is necessary for a more effective and long-lasting smart city model-based system that can monitor energy use[6]. Tenaga Nasional Bhd (TNB), Malaysia's electric utility provider, proposed installing smart meters in roughly 8.3 million households by 2021 and 9.1 million households by 2026. (Landau, 2020). It allows for a two-way flow of information between customers and providers, resulting in greater control and efficiency (Pereira et al., 2015). (Muralidhara et al., 2020), propose implementation IOT to bridge the gap in devices in energy consumption data. The devices can measure electrical appliance and the main without causing any interruptions. Pimple et al (2021), introduced an alternative way for measuring billing energy consumption. this research focusing on implementing GSM module that will send all information through mobile network. Azmi et al (2018), focusing on modelling three-phase energy meter using MATLAB/Simulink that can observe the behavior of energy consumption. but there is still a gap of this research, such as control the energy consuming via relay, or modelling Prepaid Single-phase energy meter using MATLAB/Simulink for better understanding. This study displays result of the measurement current and real power with a variable resistance. Also, analysis of energy consumption from the enhanced of energy consumption.

Prepaid Energy Meters allow power providers to collect electricity costs from customers before they use them. It features prepaid recharge and information sharing with utilities on client usage facts (Jain & Bagree, 2011). Prepaid systems are like mobile phone charging systems. The customer purchases a recharge card and receives some energy units in exchange for the remaining balance. The quantity decreases with each unit of energy spent, and when it reaches zero, the power supply is immediately shut off. Thus, the consumer needs to recharge to keep the power been supplied to their household. This system can be combined with, the integrated energy meter with GSM SHIELD SIM9000 and Relay. Where the GSM modem will send the information through mobile phone and relay will control the supply through energy meter. Also, by modelling single-phase prepaid energy meter will give a better understanding to the operation of proposed idea. The importance of this study to control the energy consumption and avoiding excessive electrical usage for Single-Phase prepaid Energy Meter.

Methodology

The traditional system involves a person for collecting the reading manually for each energy meter that been applied to every consumer. The Plausibility for manual error with an increasing number of consumers (Peter & Iderus, 2021). Therefore, the manual work was replaced by using analog meter reading along with Arduino UNO and GSM SHIELD SIM900 module. This project cover from simulation studied using MATLAB / Simulink and prototype design of Prepaid Energy Meter. the simulation studied was conducted on single phase energy meter using MATLAB / Simulink software to analyses the performance of energy meter system.

Flowchart of Project

Figure 1 shows the flowchart process of modelling single-phase energy meter by MATLAB/Simulink. Started with creating a block for measured current and voltage. by using equation (1)- (2) to get the value of active and reactive power. If the power factor is not unity, the block model must be rearranged. After that, equation (5) will help to generate the energy consumption (Loss et al., 1998). Then, by comparing balanced from user defined with the value of threshold will allowed a switch break block to connect supply through the circuit.

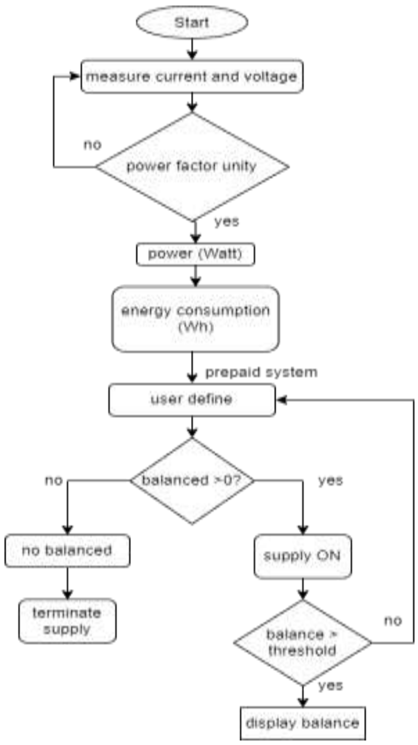

Figure 1: Flowchart for modeling single-phase prepaid energy meter using MATLAB/Simulink.

Figure 2 shows the flowchart for prototype of Prepaid energy meter. The fist process is by initialized the system, where GSM SHIELD SIM900 and I2C LCD are booting. Then, the user needs to set unit cost/balanced. The microcontroller will read the data and stored to Electrically Erasable Programmable Read-only Memory (EEPROM). Then, it would initialize the relay to allow current flow to the load. GSM module would send a message to user phone when balanced usage was reach threshold valued. Then, the relay would close when the usage reach 100%. The process would repeat when the user recharges their balanced.

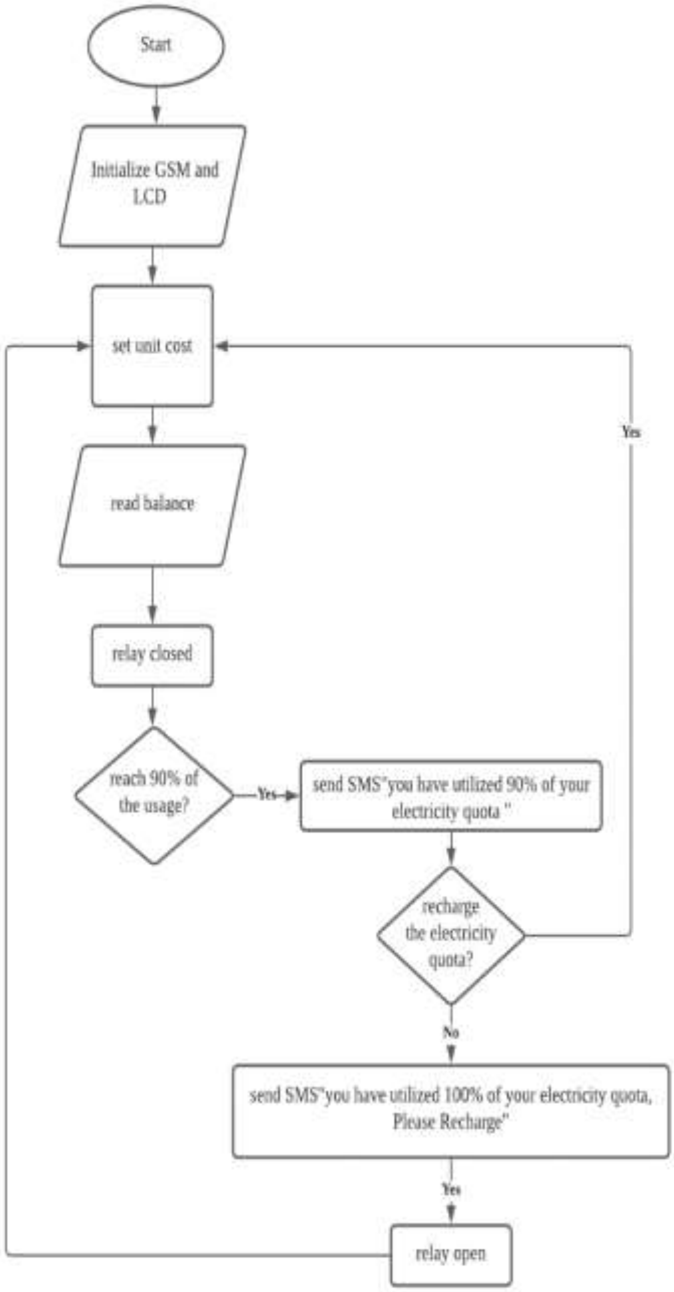

Figure 2: Flowchart for prototype single-phase prepaid energy meter

Mathematical Modelling

The relationship show the mathematical modeling energy metering and measurement of the related parameters.

$$V_{RMS} = {(I \times R)}/{\sqrt{2}} \tag{1}$$

$$P = I \times V \tag{2}$$

$$PF = \cos\theta \tag{3}$$

$$\cos\theta = V\angle\theta \; - I\angle\theta \tag{4}$$

$$E = \int_{t0}^{t1} vit\, dt \quad (5)$$

$$R_b = R_a - E \quad (6)$$

Where,
V = voltage, V
I = current, A
R = resistance, Ω
P = Active or real power demand
Cos θ = load power factor
E = energy consumption in time t
T = real time (s)
R_a = recharge amount
R_b = total recharge balanced

The active power is the average of net energy that transmitted but the reactive power is zero. Where is it no energy is transmitted or it in smaller value. Therefore, the reactive power keeps swing back and forth from the source to load (Aziz et al., 2013). Thus, it can be seen for domestic consumer only to pays for the energy that been convert from the active power. Utility company only charges for penalty if it given poor power factor. Which is from the reactive power.

Simulation Model using Matlab/Simulink

Figure 3, 4 and 5 shows the simulation for single-phase prepaid energy meter that provided energy consumption on different load used.

Energy measurement block: to measured energy consumption unit with respected to time.
Voltage and Current block: produce the value of voltage and current from the load connected.
Power Factor block: operation for calculated power factor from the phase angle difference between voltage and current.
Recharge subsystem: user define for how much ringgit they want to be used and converted to kwh.

The recharge subsystem will allow the user to insert how much (in RM) the used for converting to kwh. Then, when the simulation was run. AC source will supply the voltage to the load where the energy measurement subsystem would display the energy consumption with respect to the time. Until the balanced reach the value of threshold been set, the circuit breaker will change from 1 to 0. Thus, it will stop supply through the circuit.

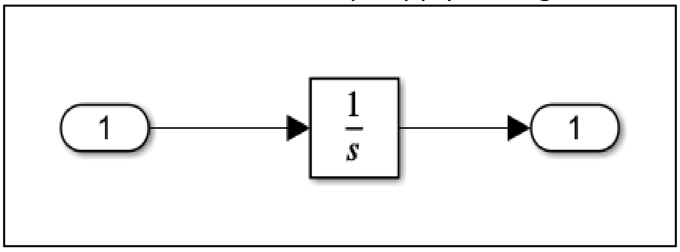

Figure 3: energy measurement block.

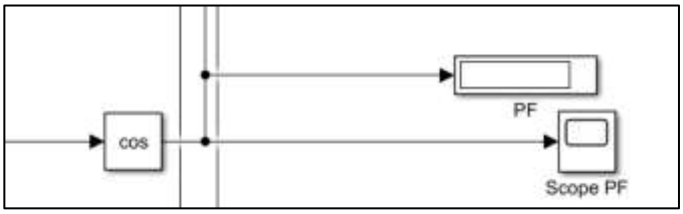

Figure 4: Power Factor block

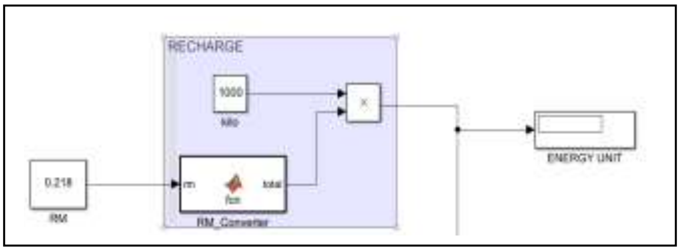

Figure 5: Recharge Ringgit to Energy unit Converter Subsystem

Prototype Design

Figure 6 shows the prototype design consist of Arduino UNO, I2C 16x2 LCD, ZMPT101B voltage sensor, ACS712 current sensor, relay, and GSM SHIELD SIM900. The design of this prototype is to improve a single-phase energy meter that capable of measuring data consumption in the household. The microcontroller will get information from the voltage and current sensor that connected from AC supply trough analog energy meter. It will measure the voltage, current, active power, and the power consumption. Then, the prepaid scheme of Arduino will read the credit values (RM) that stored inside EEPROM. Then, the system would check the remaining balance, if the balance is more than the set value of threshold, system allowed the relay to turn on the power supply. Thus, it would help to control and more organized the power consumption in household.

Prepaid Method: one of the methods to control the used energy consumption.

Electrically Erasable Programmable Read-Only Memory: allow users to erase and reprogram stored data repeatedly in an application.

Hall Sensor: allows non-contact detection of direct and alternating current, using a magnet-electric converting element. It will help to minimizes power loss of the target current circuit.

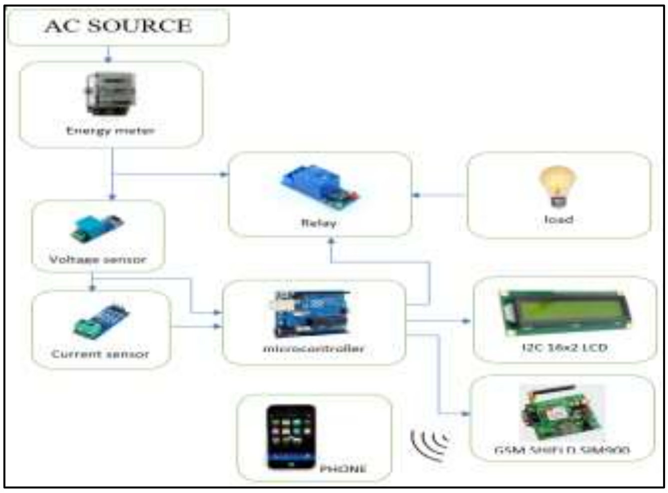

Figure 6: Block diagram of prototype Prepaid Energy Meter.

Results and Discussion
Simulation Part

Figure 7 shows the evaluation of consumer loads with a various value of resistances from 100 Ω to 1000 Ω that associated with proposed energy meter. The graphical behavior of the energy meter was recorded. Table 1 shows the measurement of active power of the reading and estimations. From figure 7 shows the simulation result for voltage is 240.8V. Also, it is observed that the voltage for entire resistance is constant as varying resistance load from 100Ω to 1000Ω. This is satisfied by using the ohm's law states that the current is directly proportional to the voltage and resistance is inversely proportional (Noppers et al., 2016). Furthermore, in the energy meter system shows the decreasing resistance value, will higher the current flow and voltage become constant.

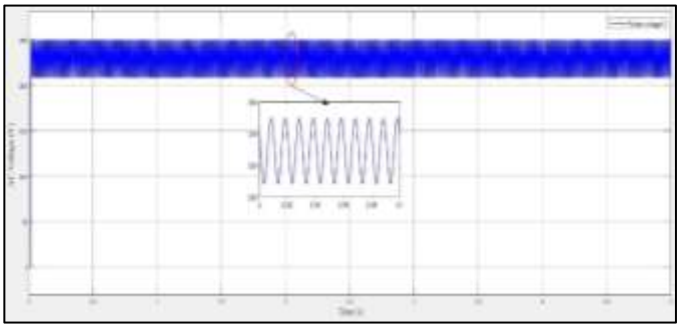

Figure 7: Waveform of measured voltage of 100Ω

Figure 8 shows the value of current is decreasing from 2.4 to 0.24 ampere as the value of resistance decreased from 1000 Ω to 100 Ω. Same goes for active power, the observation from figure 9 shows the value of active power increased when the value resistance changed from 1000 Ω to 100 Ω from 57.97 Watt to 579.6 Watt. Satisfied by using P = IV, the value of power been control by the voltage and current injected. Figure 10 below shows the power factor is unity(1=unity). Thus, the load used in this system modelling is purely resistive(Landau, 2020).

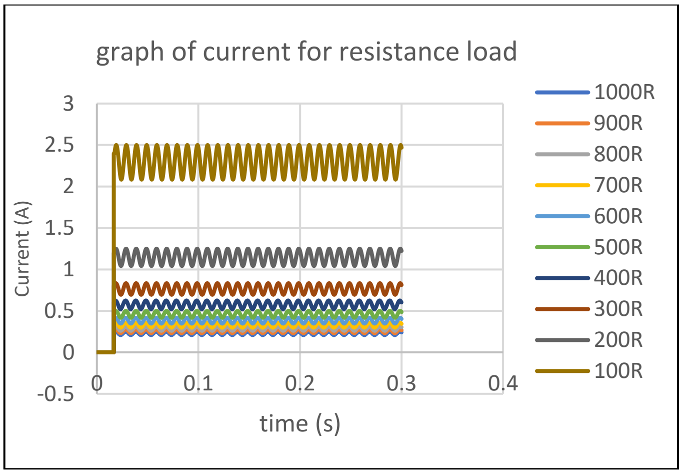

Figure 8: Varied current between resistance of 100Ω to 100Ω

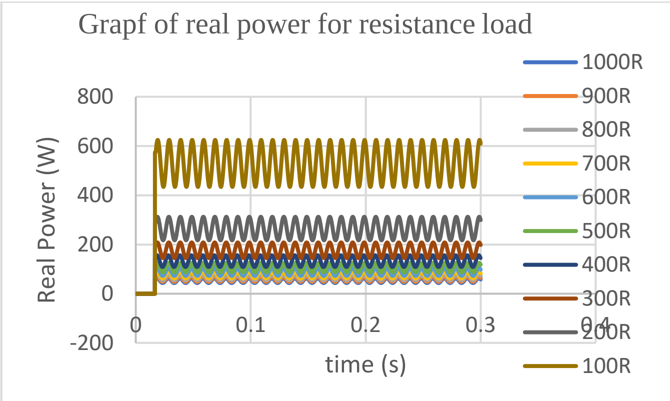

Figure 9: Varied active power between resistance of 100 Ω to 1000 Ω

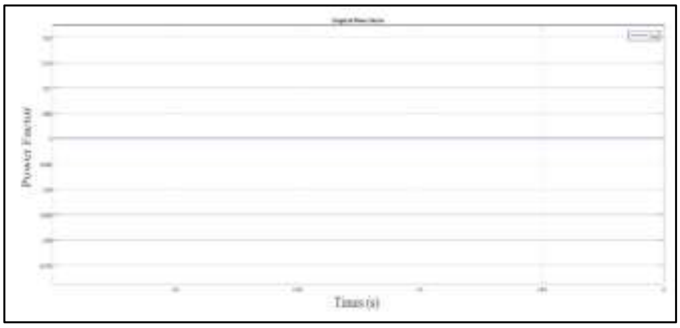

Figure 10: Power Factor Waveform

Table 1 shows the simulation of consumer's load for various values of resistance from 1000 Ω to 100 Ω. It is observed that the value of current (A) and real power (W) depends on the load resistance. The value of real power is proportional to the current.

Table 1
Measurement of Current and Voltage under Varying Resistance

Resistance (Ω)	Voltage (V)	Current (A)	pf	Active power, load,W	Energy (Wh) (20 hours)
1000	240	0.24	1	57.97	1058
900	240	0.2667	1	64.41	1176
800	240	0.3	1	72.47	1323
700	240	0.3428	1	82.82	1512
600	240	0.4	1	96.62	1763
500	240	0.48	1	115.9	2116
400	240	0.6	1	144.9	2645
300	240	0.8	1	193.2	3527
200	240	1.2	1	289.8	5290
100	240	2.4	1	579.6	10580

Table 2 shows the condition where the energy consumption pattern under time-varying condition in prepaid mode. Consider one case study varying 1 kwh for a constant 100-Watt load. it can be observed by the time 11 hours, the energy consumption up to 0.99kwh. depend on the real power load will affect the time to use 1kwh. The more load been used, the faster energy consumption (Leprince et al., 2021). Tabulated value shows the increment of energy consumption and the decreasing remaining balance energy with respect of time.

Table 2
Energy Consumption under Time-Varying Condition

Time(hour)	Consume (Wh)	Balance (Wh)
0	0	1000
1	90.4412	909.55872
2	182.3689	817.6310
3	274.2966	725.7033
4	366.2243	633.7756
5	458.1520	541.8479
6	550.0797	449.9202
7	642.0074	357.9925
8	733.9351	266.0648
9	825.8628	174.1371
10	917.7906	82.2093
11	990.9255	9.0744

Figure 11, 12 and 13 shows the energy meter state and pattern of energy consumption and balance respect to time. Observation shows that, by the time 10.793 hours the energy consumption is stop increased (Ask et al., 2018). This is because, the balance that consumer apply was reached the value of threshold. By the time balance consumer reach the value of threshold been set, the switch breaker that act as a relay will open. Thus, it will become open circuit. Where there are no current through. Same goes for the pattern of the energy consumption. By the time energy consumption reach threshold value, energy consumption will stop increasing. Because of no current was through to the circuit.

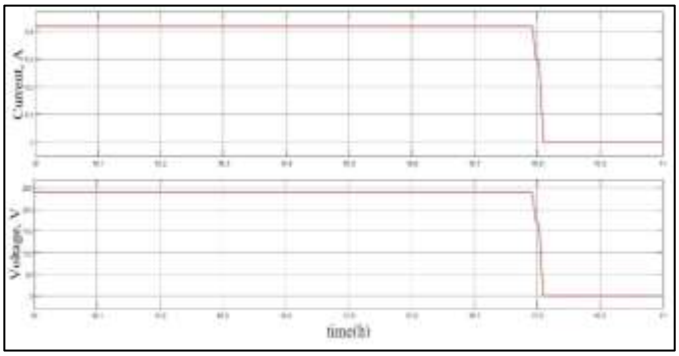

Figure 11: Energy meter state

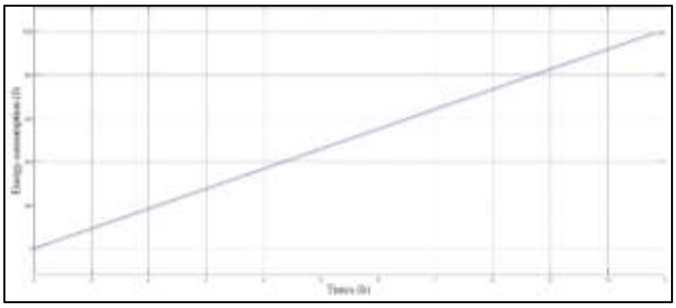

Figure 12: Energy balanced respected to time

Figure 13: Energy consumption respected to time

Hardware Part

Figure 15 and 16 shows the pattern of power consumption and voltage for prototype using Arduino Uno, relay and integrate with GSM shield SIM900 to analog energy meter. The pattern of energy consumption for prototype and simulation from Matlab are quite similar. Thus, it can be concluded that simulation and prototype have a great significant. The relay will act as switch breaker to control supply through to household. Every time user has low balance, the user will be notified by the automated SMS. Then, user can recharge their balanced by using SMS.

Also, figure 17 shows the pattern of energy consumption using 100W, 500W and 1000W. with respected to the time. It can be observe the different time every load to reach 0.1 kwh. 100W load take 2 hours until it reaches 0.1 Kwh. So, by ratio 1:10 100 W will take 10 to 20 hours to used 1 Kwh. It will give a better result if the voltage can be constant 240V. Different with 500W and 1000W will only take below 30 minute to reach the energy consumption of 0.1Kwh. Because of uses smaller load will give a longer usage.

Figure 14: Result after set value reach threshold value

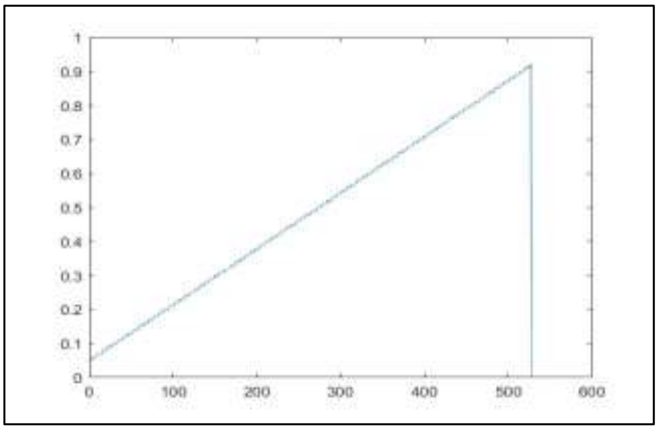

Figure 15: Energy power consumption for prototype

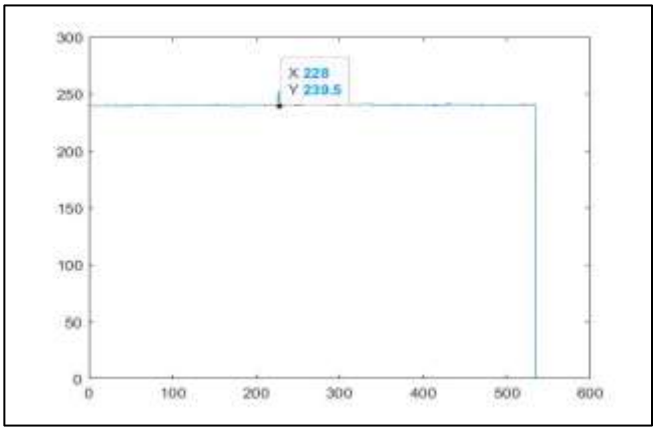

Figure 16: Waveform of voltage RMS for prototype

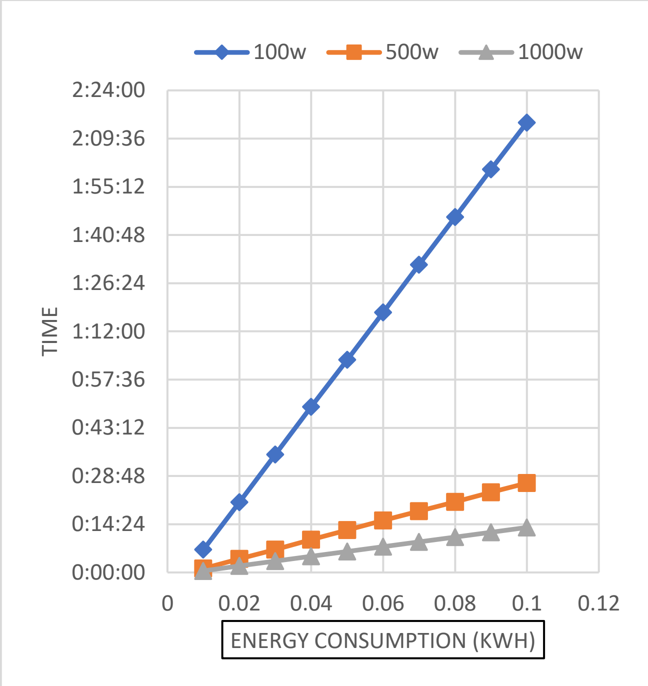

Figure 17: Energy consumption analysis using 100W, 500W and 1000W.

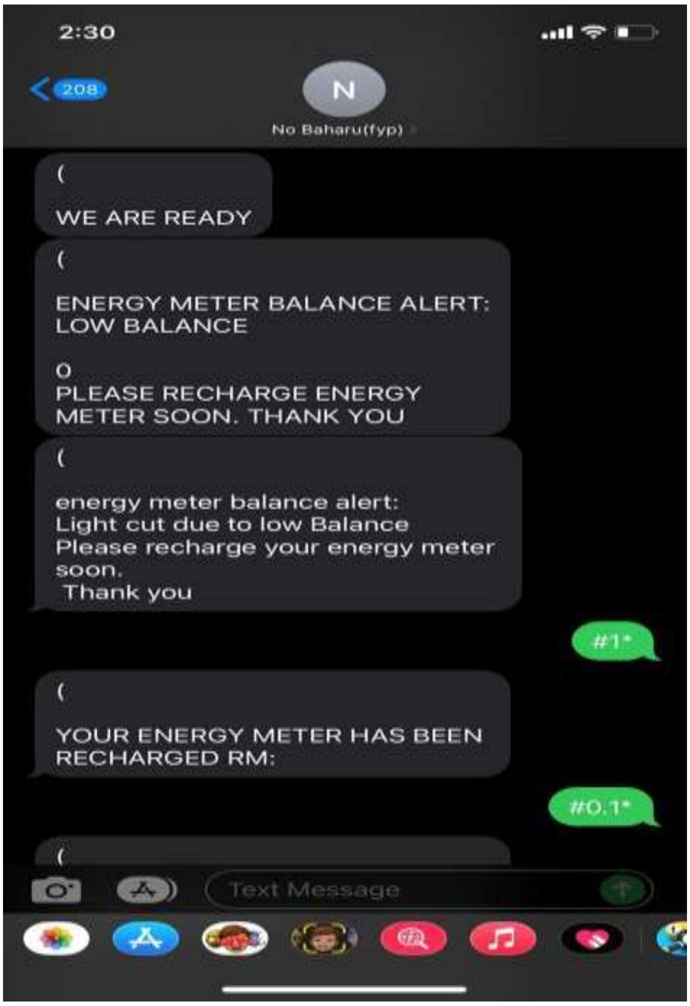

Figure 18: Recharge balance from the user.

Conclusion

The project proves that the applying prepaid energy meter system can be achieve by combining the theoretical and simulation with practical system. The needs to know energy consumption in our household is important so that energy consumption can be control. By improving this energy meter, consumer can know the energy consumption and total bill by displaying from the LCD and the GSM application on the phone. Thus, this can help to avoid any human error occur and save up a lot of manpower and time to generating the bill.

The project achieves its objective since both theoretical and simulation approach are succeeded to prove the affectedness of idea that proposed in this project. The major component that involves ensuring the system is work are GSM modem, voltage and current sensor, Arduino Uno and relay. Each of this component have its role and function as stated in previous chapter.
This project is divided into 2 parts which are simulation and hardware. The simulation used in this project are MATLAB/Simulink to design the development of Single-phase prepaid energy meter. The programming of this project is divided by each component that connected to the microcontroller which are relay and the sensor. Consumers can be more aware of their energy usage anywhere and anytime. Thus, can help saving the monthly bill of the electricity.

Contribution of this Research

Prepaid Energy Meters enable power providers to collect electricity costs from customers prior to use. Because this system can be combined with, the integrated energy metre with GSM SHIELD SIM9000 and Relay, it includes prepaid recharge and information sharing with utilities on client usage facts. Where the GSM modem sends information via mobile phone and the relay controls the supply via energy metre. Furthermore, modelling a single-phase prepaid energy metre will provide a better understanding of how the proposed idea works. This study's contribution to energy consumption control and avoiding excessive electrical usage for Single-Phase Prepaid Energy Meter.

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