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Development of Automatic Load-Shedding Strategy for Stand-Alone Photovoltaic System

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ABSTRACT

Nowadays, the use of solar energy are extremely developed and delivered worldwide. This paper presents the development of automatic load-shedding strategy for stand-alone photovoltaic system. The design of this project shows the characteristics of solar energy and operation of load-shedding strategy. The main objective of this project is to implement the load-shedding strategy as an emergency controller for stand-alone photovoltaic system. To achieve the objective, research of basic understanding related to this project is very important to understand more about the characteristics of each element in this project. The circuit of the load-shedding system is designed in the SoftCad Eagle PCB Design software. The algorithm controlling the load-shedding scheme is developed in the Arduino IDE. Then, the coding programmed is burn in the microcontroller board and installed with the hardware. Output of this project can support the DC loads and load-shedding strategy scheme is performed based on the designed algorithm.

Keywords –stand-alone photovoltaic system, load-shedding strategy, DC loads.

Introduction

The level of demand for electricity is very high as it is human necessities of life either during day time or night. Most of human daily routines such as work, economy, livelihood, healthcare and leisure depend on a constant power supply. Thus, even a temporary power failure can cause chaos, financial loss, and possible loss of life. There are several unexpected causes of power failure such as natural causes like weather, short circuit, components broken and others. However, in this modern day life, a lot of precaution steps are designed and implemented on the grid system to overcome the power failure. Microgrid systems is a new technology for improving reliability and providing alternative energy supplies to the grid system[1].The islanded microgrid operation is one of the methods to keep certain places to receive power supply. This operation is supported by load-shedding scheduling which keeping the power system stability by turn off some of the loads. For this project, the application of load-shedding strategy for islanded microgrid system during power outages is implemented in a small scope where photovoltaic (PV) technology is used as a power supply.PV generation provides a good solution for distributed energy generation especially in rural area [2]. PV systems are low maintenance, provide a cleaner, environmentally friendly alternative, and very reliable source of power. It is often used as a back-up for the grid system or operates independently without grid connection. Successful stand-alone systems generally take advantage of a combination of techniques and technologies to generate reliable power, reduce costs, and minimize in convenience. Therefore, this stand-alone PV system will supply several loads and to keep the system balance, load-shedding strategy will be implemented in this system.

Genuinely, PV entail the process regarding the conversion of the radiant energy from the sun (solar energy) directly into the electricity. Since the solar energy is the most abundant energy source on the planet, photovoltaic system can be classified as a vital technology that needs to be explored extensively in order to preserve our planet. PV sources can provide power supply to from the small electronics to homes and large commercial businesses. PV systems consist of various type of configuration such as grid connected PV system, direct PV system, stand-alone PV system and hybrid system [3].

Stand-alone PV systems is designed to operates independently, not involving with electricity grid connection [4]. These system can be powered by PV generator alone or combine with utility source as an additional source such as wind and engine-generator and these system are called PV-hybrid system.

Energy efficiency has become an issue debates where several factors may disrupt the effiency of the system such as deregulation of electrical energy distribution, the increasing price of electricity, and the implementation of rolling blackouts [5]. These factors affect the stability of the whole power system. For example when a sudden large industrial load is switched on, it will disrupt the grid system and the system become unstable. Particularly, the differences between the generated power and the load demand caused by disturbance which reduces the generation capacity of the system, thus affect the frequency of the system. The voltages become unstable when the power system unable to meet the reactive power demands of the loads [6].

The stability of the system need to be control where the load-shedding strategy can be an emergency control operation. The load-shedding strategy is designed to curtail the system load during emergency situation to control the stability of the system [7]. The loads are curtailed until the available generation could supply the remain loads. Load-shedding strategy balances the real and reactive power supply and the load demand in the system to prevent from the excessive frequency or voltage decline.

The location bus for the load-shedding will be determined based on the load importance, cost, and distance to the contingency location. The acceptable algorithms are developed based on the number of load shedding steps, amount of load that should be shed in each step, the delay between the stages, and the location of shed load.

Microgrid is an low voltage (LV) network for examples a small urban area, a shopping center, or industrial park, which the loads and several small modular generation systems are connected to it. Microgrid provides both power and heat to local loads, combine heat and power (CHP) to the system [8]. Besides that, the small modular generation systems can be referred to systems such as photovoltaic (PV), fuel cells, microturbines (MT), small wind turbines (WT) and storage devices (Fly wheels, super capacitors, batteries, and so on), which are lead to a new energy system paradigm [9].

There are two different operating conditions of Microgrid system. The first one is the Normal Interconnected Mode where the Microgrid is connected to a main Medium Voltage (MV) network, either being supplied by it or injecting some amount of power into the main system [8, 9]. The second one is the Emergency Mode where the Microgrid operates autonomously, in a similar way to physical islands, when the disconnection from the upstream MV network occurs due to planned or unplanned events for examples, maintenance actions or faults in the MV network, respectively.

Microgrid can operates either in grid connected or islanded operation mode. In the Microgrid management, it requires the balance between supply and demand of power. The Microgrid exchanges power to an interconnected grid to meet the balance during the grid-interconnected mode. On the contrary, during islanded mode, the microgrid should meet the balance using the decrease in generation or load shedding [10].

Methodology

The planning of this investigation has been described as flow chart in Figure 1.

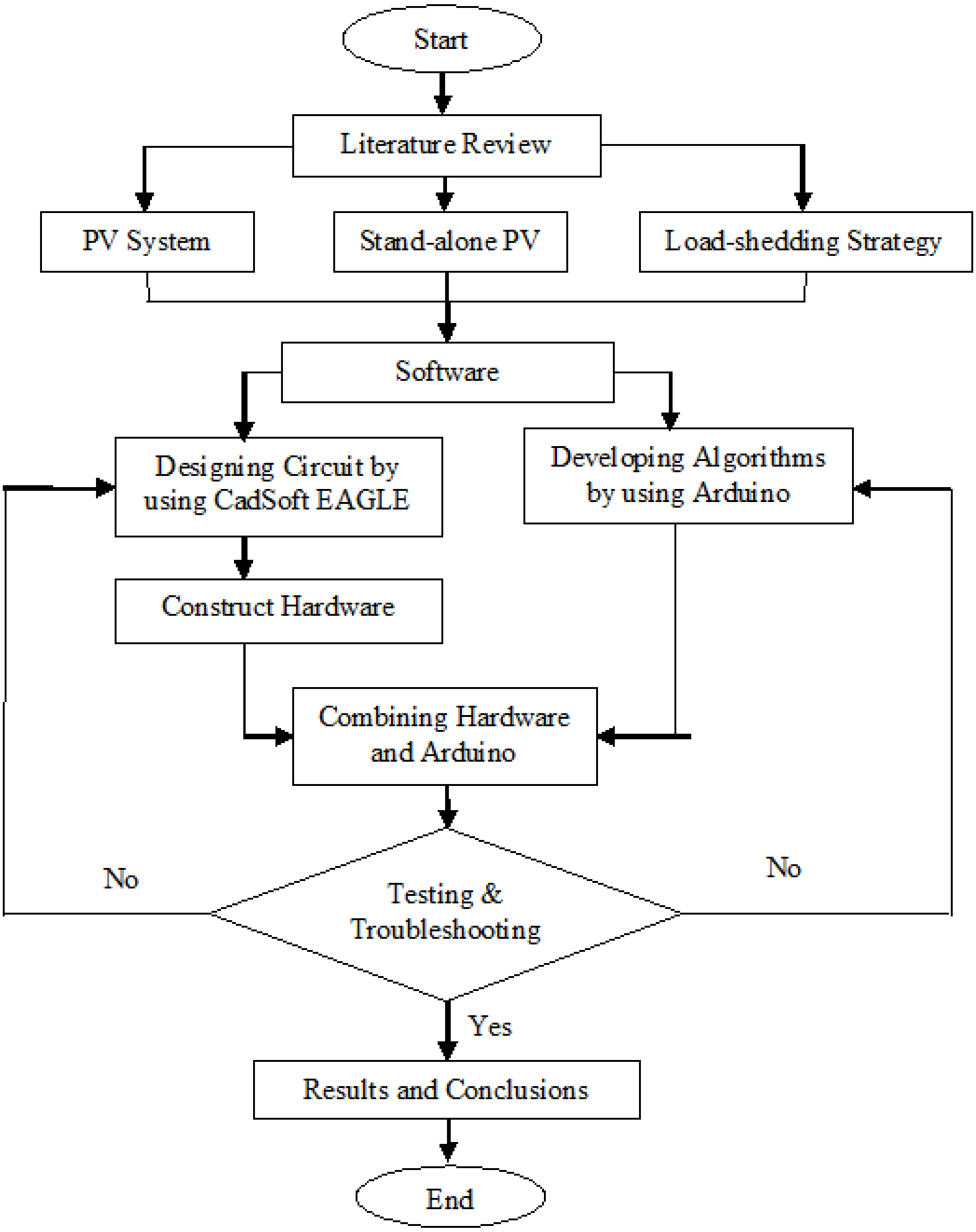

Figure 1: The flowchart of project plan

Project planning

The circuit and PCB layout for hardware is designed by using CadSoft Eagle PCB Design Software. Then the hardware is setup with two inputs, the first one is multiple AC-DC power adaptor as an utility supply, and the second one is solar panel as a PV supply. After finish setup, the connection was tested for the functional of the system.

The algorithm for controlling the loads which depends on the supply is developed in the Arduino IDE. These algorithms will decide which loads will on depends on the acceptable power range of the supply. This coding must be suitable and can work well when implemented with the hardware. After the implementation of the coding with the hardware, both will be tested and troubleshoot to ensure either the combination of both hardware and coding fulfill all the specification of the project and achieve its objectives. When the test is success all the relevant results needed are recorded and discussed.

The procedure of the circuit design

The schematic diagram of the Load-shedding Strategy circuit have been done by using SoftCad Eagle PCB Design Software as in Figure 2.

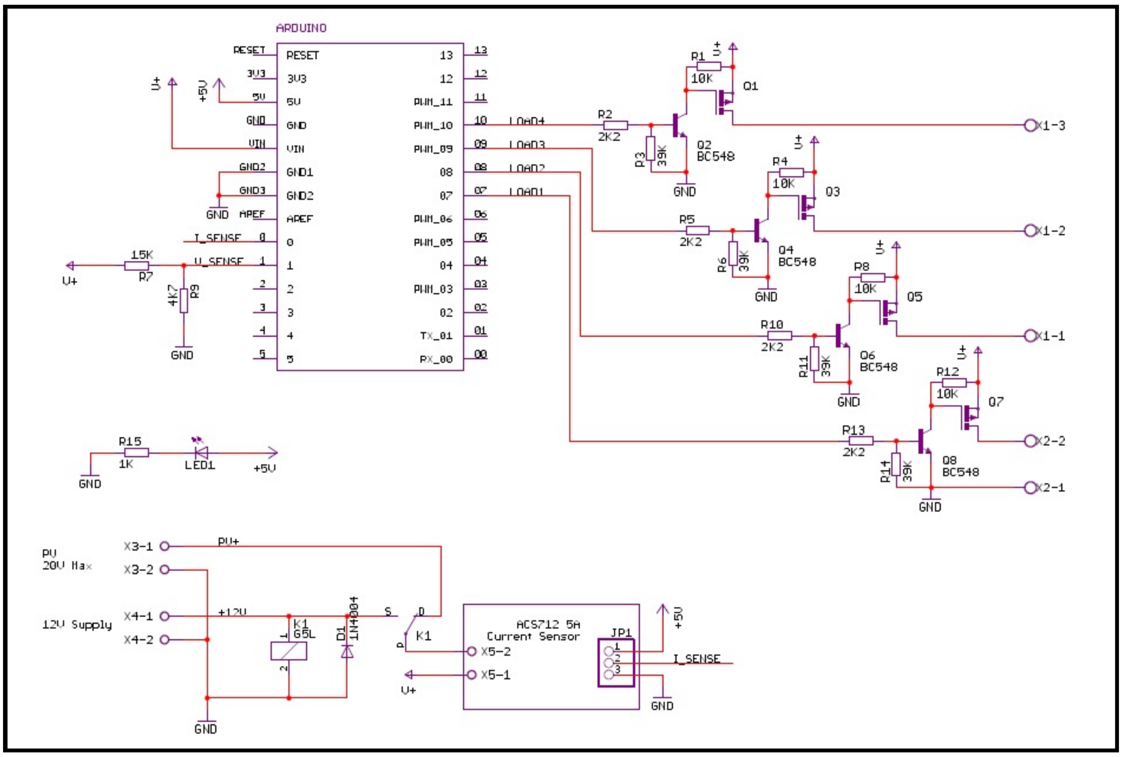

Figure 2: The schematic diagram of Load-shedding Strategy circuit

Figure 3 shows the operation process of the whole system and Figure 4 shows the procedure and algorithm of the circuit operation during the Arduino is turned ON.

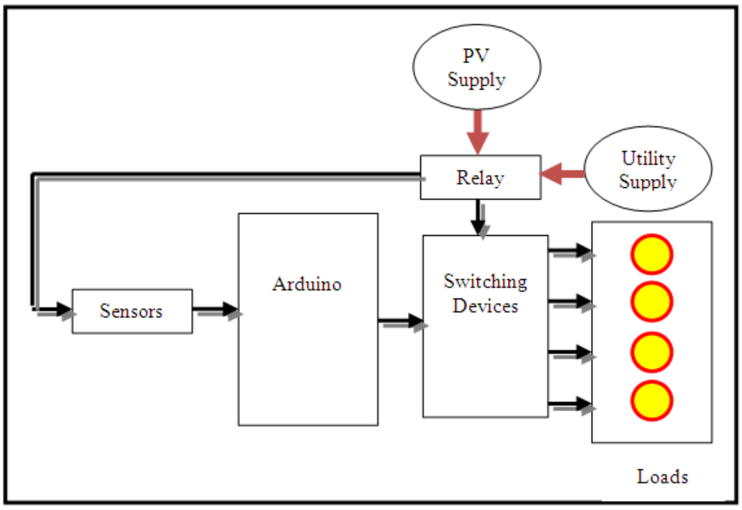

Figure 3: The process of whole circuit

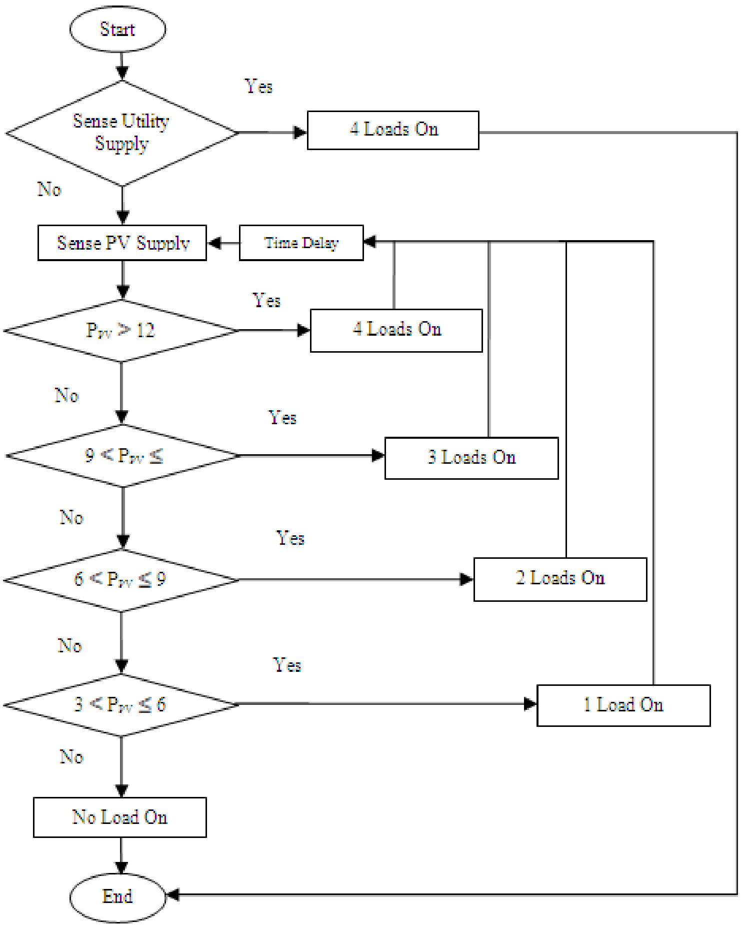

Figure 4: The procedure and algorithm of the circuit

RESULTS & DISCUSSIONS

Multiple AC-DC Power Adaptor Test Results

Power adaptor will give 12V to the system which has sufficient power to accommodate all four loads. The power supplied by the adaptor is depends on the load and the rating for current is 1.2A. Moreover, all bulbs will light up during power adaptor consumption. Nevertheless, in order to make better understanding about the load-shedding strategy, the multiple AC-DC power adaptor is varies in several values, 4.5V, 6V, 7.5V, 9V, and 12V.

Based from the results in Figure 5, there were changes in the number of lighted bulb linearly towards the changes in the value of power sensed from the supply. When the power is greater more loads can be on, while decrease in power will also decrease the numbers of bulbs light up. The highest power sensed by Arduino is 15.78W which is sufficient enough to light up the four loads. While, the lowest power draws from the supply is 3.65W which can light up only one load.

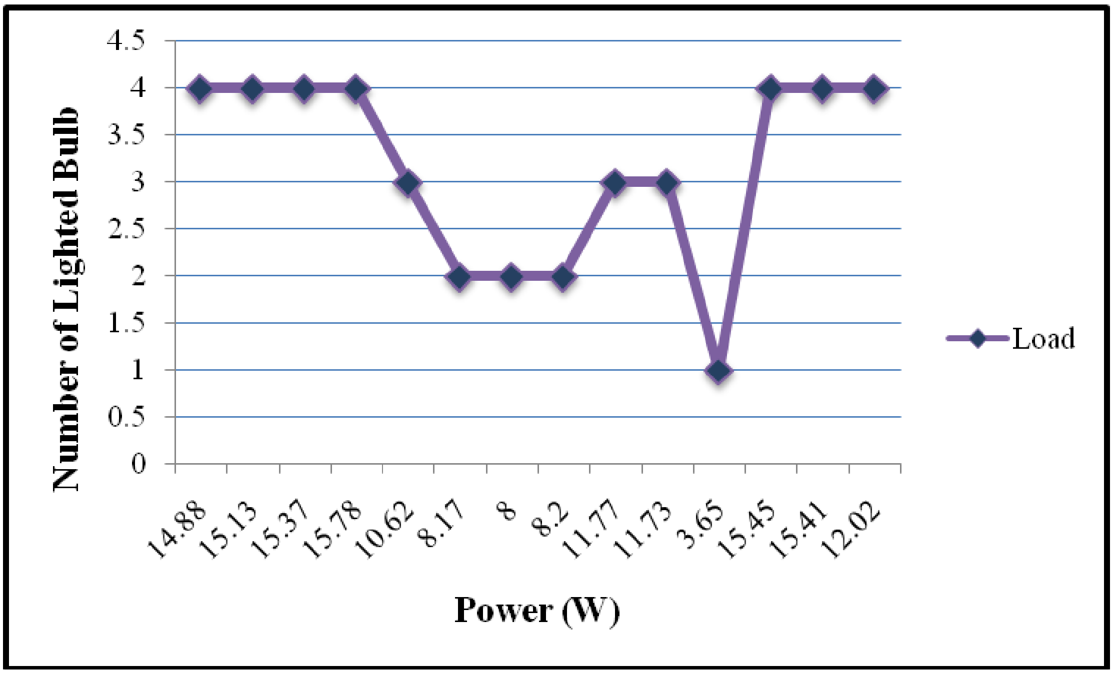

Figure 5: Graph of Multiple AC-DC Power Adaptor Test Results

Solar Panel Test Results

Experiment 1 (Morning Session)

The test was conducted in the morning at 9 a.m. where the wheather is moderate. The power draw from the solar panel is constantly small.

Figure 6 shows the changes in the number of lighted bulb linearly with the changes in the value of power sensed from the PV supply. From the graph, the powers mostly are small results in the most number of lighted bulb is only one. The maximum numbers of lighted bulb are three loads which were occurred twice. The highest power sensed by Arduino is 9.53W which is sufficient to light up only three loads. While, the lowest power draws from the supply is 3.32W which can light up only one load. The performance of the solar panel is low at this moment as the irradiance of the sun is low at the very moment. It is hardly to produce power more than 9W which can light up three loads not to mention four loads. Thus, more loads need to be shed and from the graph mostly two and three loads are shed because of the deficiency of power.

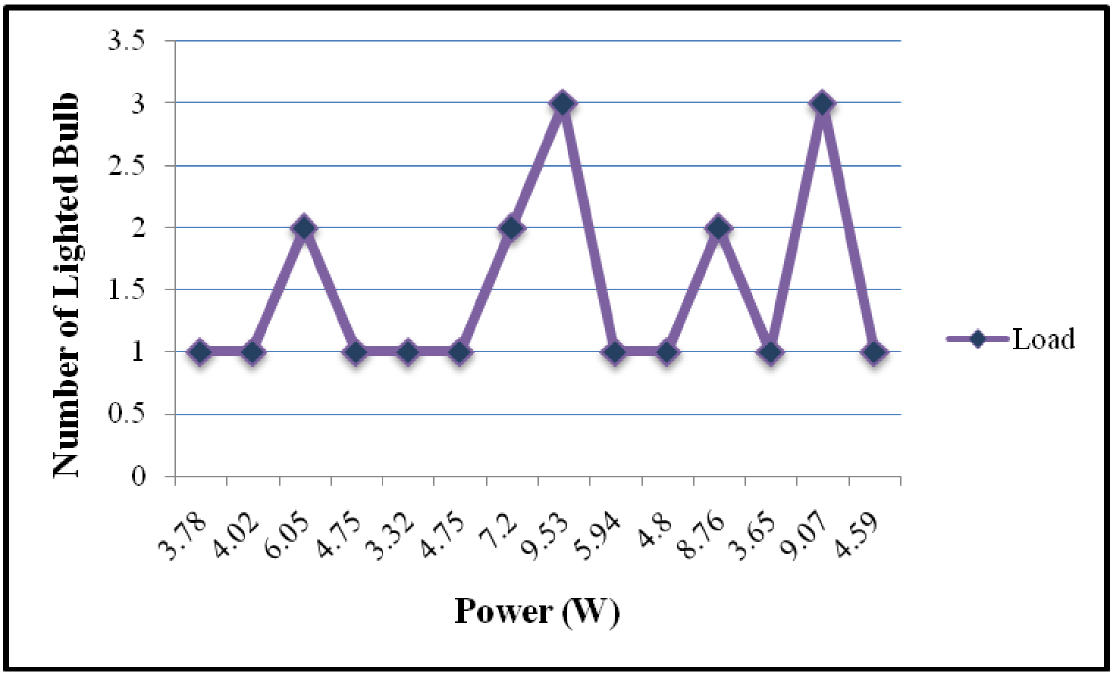

Figure 6: Graph of PV Supply Experiment 1 Results

Experiment 2 (Afternoon Session)

The test was conducted in the afternoon at 12.30 p.m. where the weather is sunny. The power draw from the solar panel is slightly higher than morning session.

Graph in Figure 7 shows the number of lighted bulb and the power generated by PV supply during afternoon session. When the power is rise, the number of lighted bulb also increases. During afternoon, the power of PV can reach up to more than 9W because of the high irradiance since it was sunny. Therefore, from the graph it can be seen that the most number of lighted bulb is two and three. This supports the theory that higher irradiances give higher efficiency to the PV supply. When the power is greater more loads can be on, while decrease in power will also decrease the numbers of bulbs light up. The highest power sensed by Arduino is 9.67W which is sufficient to light up the three loads. While, the lowest power draws from the supply is 3.32W which can light up only one load.

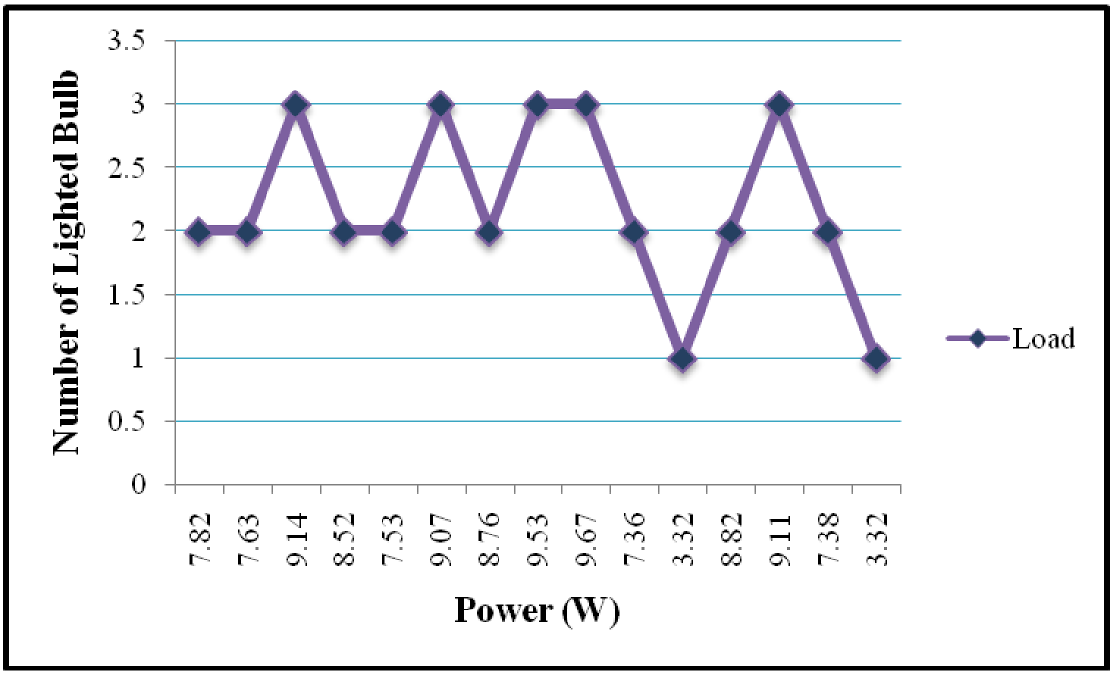

Figure 7: Graph of PV Supply Experiment 2 Results

Experiment 3 (Evening Session)

The test was conducted in the evening at 5.30 p.m. where the weather is partly cloudy. The power draw from the solar panel is slightly lower than in the afternoon.

From the graph in Figure 8, it can be seen that the average power generated by the supply is in the range of 6.85W to 8.78W where the number of lighted bulb is mostly two. The highest power sensed by Arduino is 10.62W which is sufficient to light up the three loads. While, the lowest power draws from the supply is 3.42W which can light up only one load. During the test is conducted, the weather was partly cloudy. The power is not constant and mostly the power generated can only light up one to two loads. Three loads were rarely light up which occur twice only. The performance of the PV in the evening slightly similar to the performance of the PV during morning. However, the power generated in experiment 3 is slightly higher than experiment 1. Therefore the number of load shed in the evening is less than in the morning. The variation of power might be influenced by the irradiance and the temperature at the moment.

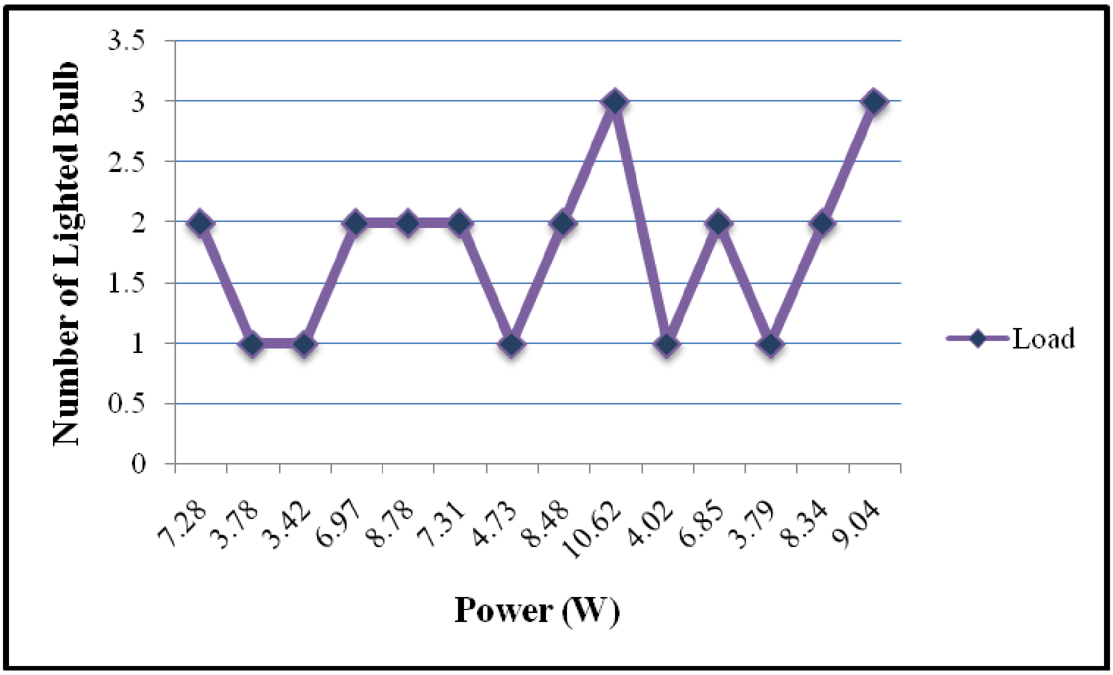

Figure 8: Graph of PV Supply Experiment 3 Results

Combination of Multiple AC-DC Power Adaptor and Solar Panel Test Results

This experiment was conducted using both supply which are power adaptor and PV supply. The experiment is conducted to observe the operation of the system when the power adaptor gave sufficient supply to the loads, however suddenly the power adaptor was off and the PV took over to supply the loads.

From the graph in Figure 9, it can be seen that from the first data up the fifth data, the loads were supplied by the power adaptor. During that time, the number of lighted bulb is four since the power generated from power adaptor is sufficient to support all four loads. The maximum power generated by the adaptor was 15.13W while the minimum power generated was 13.78W which is still can supply the four loads. Suddenly the number of lighted bulb is decreased to two because at this moment, the power adaptor is turned off and at the same time the PV supply is turned on and supply the loads. The graph shows the variation in number of bulb lighted up that occurred because of the values of power generated by the PV supply are not constant.

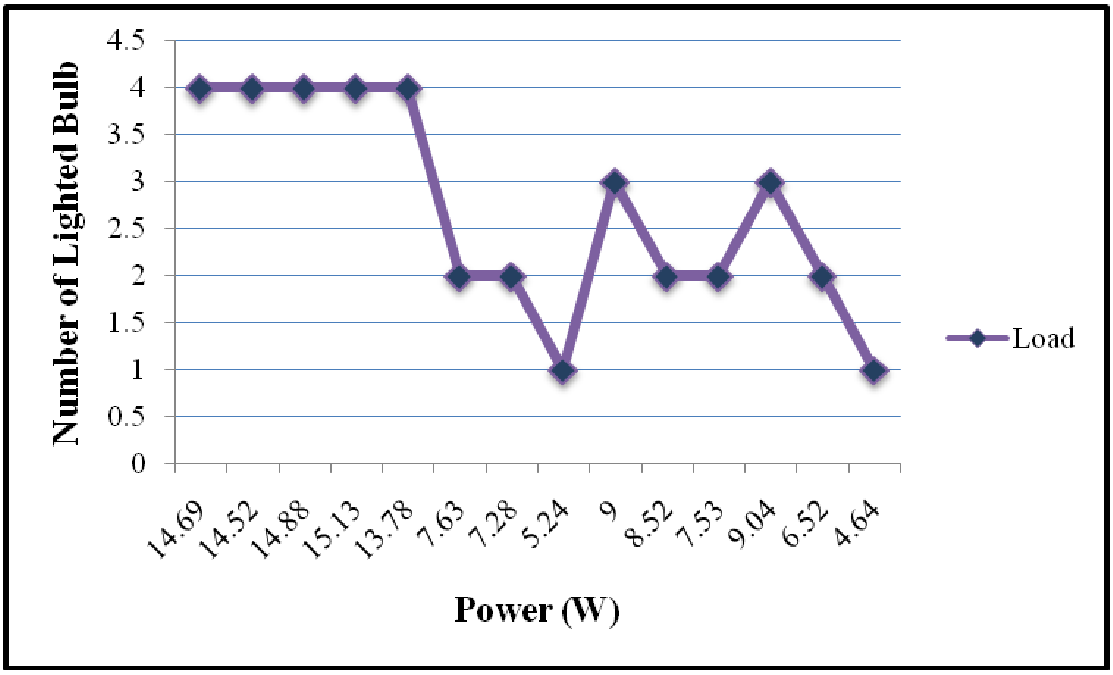

Figure 9: Graph of Combination of Multiple AC-DC Power Adaptor and PV Supply Test Results

Conclusion

An automatic load-shedding strategy for stand-alone photovoltaic system was designed using the SoftCad Eagle PCB Design Software for schematic design and PCB layout of the hardware prototype. All the components were set up and the hardware was constructed and tested successfully. The test results show the loads been shed when the power is smaller than the load demands. The load-shedding strategy operation was executed based on the algorithms programmed in the Arduino IDE. The algorithms were developed to control the load-shedding operation by using power parameters. The supplies used are multiple AC-DC power adaptor and solar panel which have different performances.The performance of the PV supply is less efficient than power adaptor since the maximum number of bulb that can be lighted up by the PV was three. While the power adaptor can light up all four loads, solar panel has different power generated within different time, morning, afternoon and evening. Furthermore, the performance of solar was affected by the irradiances of the sun and the surrounding temperatures. The higher value of temperature gives lower efficiency of the PV systems. However, the irradiant is the factor that would make the PV system more efficient where the higher the value of irradiant, the higher the efficiency of the PV systems. During islanding mode, the power balance between supply and demand was match at the moment. The results show that the proposed load-shedding scheme can regulate the power supply and the load demand very well. In addition, these results indicate that the load-shedding strategy can contribute to improve the control capability.

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