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A Self-Diagnostic System for Photovoltaic Based Highway Signage Boards and Warning Devices

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Abstract

Federal highways and state roads in Malaysia are sites of most traffic accidents. One contributing factor is the lack of or low visibility of road signage at dangerous bends or road corners. It is very important to have safety warning signage at strategic locations to warn drivers on conditions or hazards ahead by cautioning maximum allowable vehicle speed limit. However, signage boards alone by themselves are not enough. The relevant authorities have added flashing beacons to enhance visibility but the availability of on-grid power supply often hinders their installation. This is now a non-issue with the advent of solar power. With emerging flashing beacon signage scattered over a wide area, there is an operational need to monitor their performance status remotely for timely effective maintenance and repair. This paper describes the development of a smart self-diagnostic algorithm for a wirelessly monitored autonomous solar powered highway flashing beacon.

Keywords: Flashing beacon; Warning devices; Self-diagnostic algorithm; Wirelessly monitored; Solar powered

Introduction

Fossil fuels are fast depleting reserves at an alarming rate and causing serious global environmental issues. For the past decade, researches have started to explore the vast potential of tapping into green and sustainable renewable energy, one of which is solar energy which converts sunlight into thermal or electrical energy using photovoltaics. When implemented in a system it is called a solar electricity generating system. It consists of a solar panel, charge controller, battery, inverter and load.

All of these components are designated based on user requirements, scale of the system, location as well as its intended application. One such example can be found in the roadway safety signage. The relevant local authorities have taken many initiatives to enhance the visibility of signage by introducing flashing warning devices or beacons. Apparently their use has helped to reduce accidents. Recently, more efficient and affordable photovoltaic based systems have promoted the installation of many standalone road safety and warning devices in areas without electricity.

PV based LED signage boards and flashing warning beacons are now a familiar sight on our highways. The challenge is how to operate them reliably round the clock; day in, day out, especially during night time, since the amount of solar electricity generated depends on the availability of sunlight throughout the day. Then they have to be maintained, serviced to stay functional and useful.

There are many factors that affect the performance of a PV system; such as solar position, weather, dust and rain water stains on the surface of the solar panel. All these must be taken into consideration when the PV based LED signage system is installed.

Consequently, a LED signage board or flashing warning beacon will be efficient and effective if the PV system is sized properly and the path of the sun is tracked to maximize the amount of sun shining on the solar panel. Without a diagnostic in the system to do health check of the installed LED based signage or flashing warning beacon, the maintenance personnel will not know the performance of the system. Therefore incorporating a self- diagnostic test is essential and useful in alerting system maintenance or service, as well as to optimize the system.

This paper presents a study on PV based LED signage boards and flashing warning devices on federal roads and highways. It includes a smart self-diagnostic algorithm designed to monitor, measure and report the operational status of such a prototype system installed on the highway.

PV based signage and warning devices

Road regulations and highway codes play a vital role on road safety. They raise public awareness, giving ample warning of hazardous road conditions such as sharp corner, slippery road, winding terrain, or a pedestrian walkway ahead. Researchers have found that a warning sign combined with a flashing device is more effective than just the warning sign, so more and more of these combinations are being implemented [1]. Flashing devices traditionally use incandescent light bulbs with high power rating. In the solar powered flashing beacon system, incandescent bulbs are not practical due to limited power generated by solar panels. As the general trend already shows, they will eventually be replaced by light emitting diodes (LEDs) [2]. LED units configured in an array are smaller, extremely energy efficient, brighter and last longer.

PV systems are basically on-grid or off-grid. An on-grid system is a semi-autonomous electrical generation system which links to the mains to feed excess capacity back to the utility grid. There is an inverter connected to the solar panels that converts direct current into alternating current with an ability to synchronize and interface with a utility line. The system will stop to work when there is a failure at the utility grid. This is not the case with an off-grid system which is independent of the utility grid and has a battery to store energy produced during the day. In this project the flashing beacon is an off-grid, standalone system.

The Table 1 compares the advantages and disadvantages of an on-grid and off-grid PV system.

Type of PV system	Advantage	Disadvantage
On-grid	Constant power and performance	Expensive
		No backup system
	Reliable	Difficult to install
Off-grid	Less expensive	High maintenance cost
	Easier to install	Low efficiency
	Have backup battery	Not reliable

Table 1: The advantages and disadvantages of the On-grid and Off-grid system.

The off-grid PV flashing beacon is a better choice as it is more cost effective in the long term, easier to install and works solely on solar energy harvested when the sun shines. During overcast days and at night it draws its power from the storage battery. Therefore, the PV flashing beacon module and it electronics is a small Solar Electricity Generating System (SEGS). Figure 1 below shows solar powered beacon project.

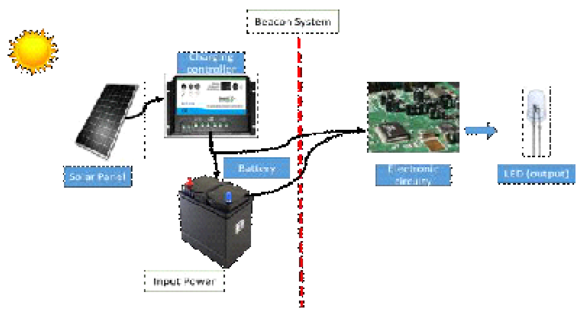

Figure 1: SEGS for beacon system.

The power output of a solar energy system varies according to irradiance and local functioning conditions. It is therefore an important challenge to design the PV system for continuous, reliable power under all anticipated environmental conditions.

Egido and Lorenzo [3] proposed creating a reliability map for each LOLP value. The main disadvantage is the difficulty in applying it to locations where there is no daily radiation series data available. In this case, the authors suggested recalculate all the coefficients in the model to avoid significant loss of accuracy. On the other hand, Markvart et al. [4] approximated PV sizing based on observed time series of solar radiation with the reliability of photovoltaic supply advantage factored into the length of time series data near the site where the PV system is being installed. The resulting procedure is then summarized in a sizing curve. Latest more advanced methods included the use of artificial intelligence (AI) techniques, fuzzy logic and artificial neural networks. Conti et al. [5] was one of the first to propose the application of AI techniques in the PV system sizing. While Mellit [6] evaluated an improved approach for modeling of the optimal sizing parameters in isolated sites where meteorological data are not available. The advantages of AI-based techniques are that they offer a powerful alternative approach to conventional physical modeling. These techniques do not require knowledge of the internal system parameters and involve less computational effort.

However, one of the components in AI-based techniques requires the study of solar geometry to boost the harvesting of solar energy. For maximum solar insolation, the solar panel module has to be positioned in the best direction and angle to the sun tracking the earth's elliptical path around the sun [7].

To incorporate a self-diagnostic test feature in the off-grid PV beacon system requires two basic components- hardware and software. The hardware part includes solar panel, a pulse width modulation (PWM) charging controller or smart maximum power point tracking (MPPT) controller, a microcontroller, lead acid battery, different sensors, light emitting diodes, communication modules and a PC.

Two types of charging controller are studied for their suitability. In the final analysis, a MPPT is preferred as it is more efficient and offers more features. In particular it can adjust its input voltage to harvest the maximum power from the solar array and then transform this power to supply varying voltage requirement of the battery plus load [8]. By comparison, the PWM is just a switch which connects the solar panel to battery. Furthermore, a low power, low cost MPPT model investigated comes with ability to monitor PV input voltage, charging current, charging power, battery voltage and RS232 communication for ease of interface to the microcontroller [9].

Another important component in the PV flashing beacon system is the storage battery. A battery stores excess energy generated by the solar array during bright days of high insolation and discharges stored energy back into the load at night or on cloudy days Correct battery type selection and sizing is critical to the success of this particular application. The battery has to be able to accept the highest power output from the solar panel without overcharge damage. The key elements in the battery selection are operating temperature variations, environmental temperature extremes and daily usage, charging and discharging rate, voltage regulator design, safety and low maintenance. The lead-acid battery is the ideal storage battery for a standalone photovoltaic system when connected to a solar charge controller. It has significantly lower initial investment costs and is commonly available. Furthermore, battery sizing is easily calculated from the system load and battery capacity [10].

For the transfer of PV system data monitored, control of the self-diagnostic test program, and management of set-up; a wireless communication link to a base station PC is proposed. Some of the options studied include ZigBee, TelosB mote, GSM and Ethernet.

Based on cost, availability, open source and user friendly program codes and relevance to the research, the ZigBee platform is selected [11].

The author is also motivated by the work of T. Ramachandran and team who successfully designed a renewable street light system using

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ZigBee wireless communication for monitoring purpose [12]. However, this project did not consider the PV sizing and solar geometry which will affect the power output of the solar panel. This is important because the solar radiation fluctuates throughout the day. Therefore, the performance of the system will not be consistent. Besides that, MPPT is not considered in this project which can extend the battery lifespan and reduce the power loss in the system. The graphical user interface (GUI) provided is not user-friendly.

Another related research for this project is a self-diagnostic system for predictive maintenance of traffic light control system which carried out by Ekene et al. [13]. Short message service (SMS) via GSM is used to communicate with the operator when the intensity of the traffic light is not function as desired. This system is not using any renewable energy source and will only report whenever there is faulty at the output where the intensity of the traffic light might cause by other factors.

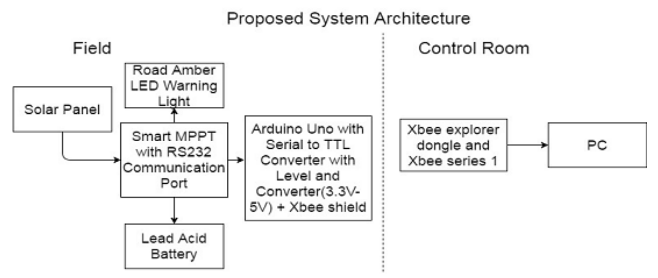

Figure 2: Proposed main hardware.

Furthermore, a traffic safety products manufacturer from the USA - K&K system has come out with several products for highway signage boards and warning devices [14]. The beacon system that offered by this company is included with MPPT. Besides that, another control system called crosstalk is presented for monitoring the performance of the solar beacon wirelessly without walking outside. The control system can be communicated through two forms either cell modem or radio. All the information will be shown in the GUI provided by the K&K system company through World Wide Web. However, PV sizing is not mentioned in the design concept and solar geometry is not considered. As mentioned earlier, PV sizing and solar geometry are very important as it will affect the performance of the system which indirectly leads to the safety of the road user. Moreover, the price for the beacon system including with the control system is not mentioned on the web page and expected to be very expensive.

After extensive search, there is no document or specification relating to PV based flashing beacon or any roadway beacon found or issued by the Malaysia highway authorities. To this end, the US Department of Transport, Federal Highway Administration road safety standards defined in the Manual on Uniform Traffic Control Devices (MUTCD) is adopted for the PV powered flashing beacon [15,16].

Methodology

The conceptual architecture of the project revolves around 2 main components: hardware and software. Both are complimentary in function. The internet is used to browse for required components focusing on availability, short delivery time, affordability and with supporting free access to open source code software (Figure 2).

PV system parameters defined are monitored by sensors controlled and managed by a microcontroller (Figure 3). Data are transmitted wirelessly to base station PC on demand or triggered by a set clock to show system self-diagnostic test status. It can also display on the screen operating system values. The programming will be written in C++ language.

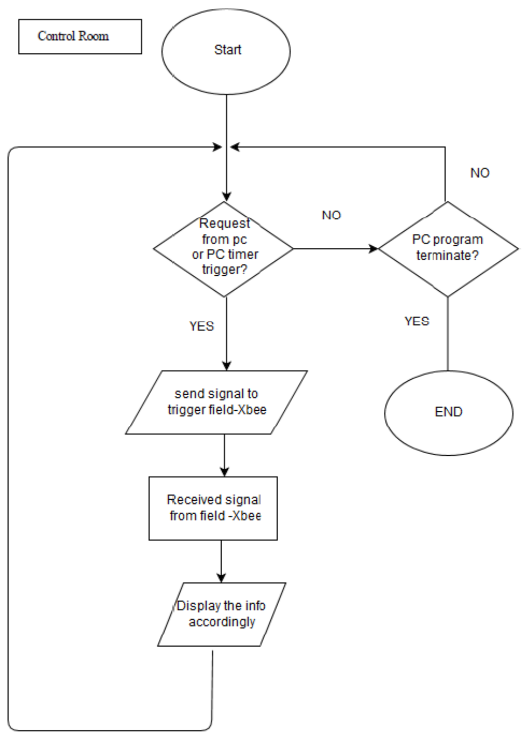

Figure 3: Programme flow chart for control room.

In the control room, there is a radio module and PC running an algorithm to monitor the end device. When the program is initiated, the PC will continuously check any request from user (Figure 4). If a trigger signal is detected, the PC will activate the field communication platform device and wait for it to respond, then standby to receive raw data sent. All data received are processed based on the performance algorithm and the GUI displays the process data accordingly. The microcontroller in the field is programmed separately from that in the control room PC. When the program runs, the field microcontroller will continuously check if a signal received from the control room PC though wireless communication platform device. When a signal is received from the control room PC, the field microcontroller will transfer data from the MPPT, flashing beacon, and other embedded sensors back to the control room PC via the radio module.

Results and Discussion

The system demonstrates its capability to run on solar power autonomously and the base station PC has the ability to monitor PV, battery and load- current, voltage and temperature in real time (Figure 5).

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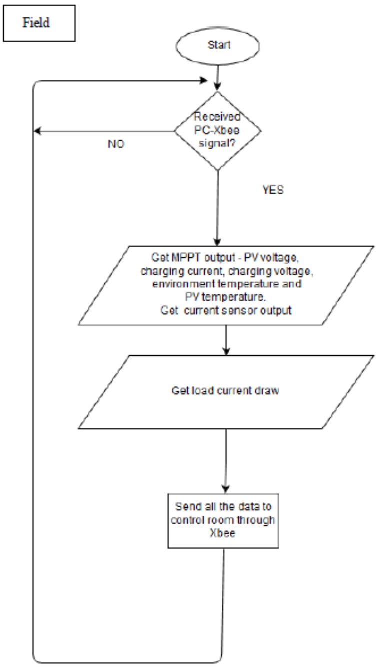

Figure 4: Programme flow chart for control room and field unit.

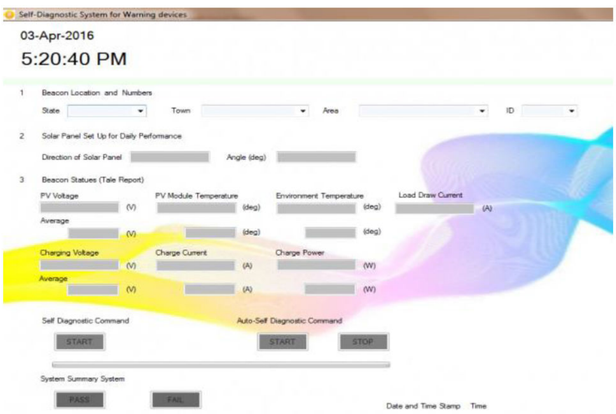

Figure 5: Graphical user interface.

The graphical user interface (GUI) is designed by using Microsoft Visual Basic software as mentioned earlier. The user is able to view all data that transmitted from the field in real time by just clicking the start button in the GUI. Instead of clicking the start button regularly, an additional feature is added to click the start button automatically in order to make the GUI more user-friendly. In addition, the diagnostic of the system is separated by daytime and night time. For daytime, system summary pass or fail is based on the average of all data that received. However, for night time, only load current draw is determined the system pass or fail due to other data is no longer relevant. Even the GUI has closed accidentally, all average data will be saved automatically to prevent average data lost. This is to make the GUI more intelligent and able to provide reliable data. Besides that, the software is designed in such a way that able to create history data in excel file. By having the history data in excel file, the user can be more accurately compare different data at specific date or month for analytical purposes.

Field test has been conducted and the performance analysis is based on the history data that have been save in the Microsoft excel file automatically by the GUI. The figures below are the graph of environment temperature charge power, PV voltage, and charging voltage versus day.

Conclusion

The objective of this project is to develop a self-diagnostic prototype to monitor and manage a solar powered signage board with a warning device in the form of a flashing beacon. Featuring a self-diagnostic test capability in the system enables technicians to service the warning device more efficiently. A prototype PV powered flashing beacon was built, it worked as expected. System data were collected in real-time. The field set-up can be monitored and viewed remotely on the PC. This makes predictive and preventive maintenance pro-active thus minimizing potential system downtime. As a result, this promotes better roadway safety, helps to prevent accident and unnecessary loss of human lives.

Acknowledgement

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