Standalone PV systems for rural areas in Sabah, Malaysia: Review and case study application

Ali H A Alwaeli, Hussain Falih Mahdi

Solar energy is the energy utilized from the sun. Either to produce heat or electricity, solar energy is a clean source of energy. The electrical aspect of solar energy is produced using a semiconductor device named "Photovoltaic" or PV. The PV technology can be used to feed the grid, making it a grid connected system or to feed close by loads separately, making it a stand-alone system. This paper aims to study stand-alone PV systems in terms of: principle of work, construction and operation for rural areas in Malaysia. A case study application has been put forward and implemented in a village in Sipitang, Sabah, Malaysia. The system produced is a stand-alone PV system with 1 inverter, 1 charge controller, 2 batteries and 4 PV panels- all connected in parallel. capital cost analysis of the system has been conducted and found that the system costs 5,171.2 USD.

Index Terms**—Solar power, Photovoltaic, Stand-alone**

I. INTRODUCTION

RENEWABLE energy research for the countries of Southeast Asia have been increasing steadily since 2009. This is due to the rapid growth in economy which is affected by the energy industry and other industries; As of January 2014 Malaysia have proven oil reserves of 4 billion barrels, making it the fourth-highest reserves in Asia-Pacific after China, India, and Vietnam. This may be a large reason for dependency on fossil fuel. Increasing imports of fossil fuel, rising of environmental concerns coupled with heavy reliance on fossil fuels and traditional biomass may cause many problems on the long term. Deploying renewable energies in order to compete with fossil fuels needs for renewable energies to be cost-effective. Therefore, more research needs to be conducted in these countries [1-11]. Policy and decision makers in Malaysia continue to help the growth of renewable energies as on the 28th of April 2011 a renewable energy bill (RE Bill) and a Bill for Sustainable Development Authority (SEDA Bill) were passed by the House of Representatives. In addition, a one percent feed-in tariff (FiT), which pays into a renewable energy fund [2]. This shows that renewable energies have a high potential for countries like Malaysia. Many communities exist in rural areas in Malaysia, these communities suffer from the lack of electricity which is a large issue for any community to have in 2016. Providing electricity for these communities is a hard task as connecting the electricity grid to these rural areas may be technically impossible or economically too expensive. Using diesel generators may harm the environment and supplying it with diesel fuel maybe too expensive for these villagers. It is necessary to conduct more studies in this field specific to Malaysia covering subjects like suitable locations, tilt angles and configurations. Also finding optimal sizing techniques for these PV-systems.

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II. STAND-ALONE PV SYSTEMS

Stand-alone PV systems are generally comprised of PV panels, inverters, charge controller and batteries. All coupled through wire connections. The PV panels are made up of modules which are in turn made up of cells. PV cells the simplest element in the system. They are made of semiconductor material which converts the energy of photons (received form sunlight) into Direct Current (DC) electricity. There are different types of PV cells depending on the material or intended applications. Crystalline and Amorphous Silicon are two famous types of PV cells. Silicon is the common material in PV cells which has an outer shell that is only half full with just four electrons making it susceptible to be affected by photons. Once a photon gives sufficient energy to an electron on the outer shell, it will cause it to leave and leave behind it a positively charged "Hole". The electron-hole pair is then the essence of creating a potential barrier. The only way for the PV cell to work is if the potential barrier is utilized. This can be achieved by connecting it to a load. One a load is connected, current will flow in the circuit [12-25]. Figure 1 shows electrical circuit representing the PV cell and figure 2 shows the block diagram of simplest stand-alone PV system.

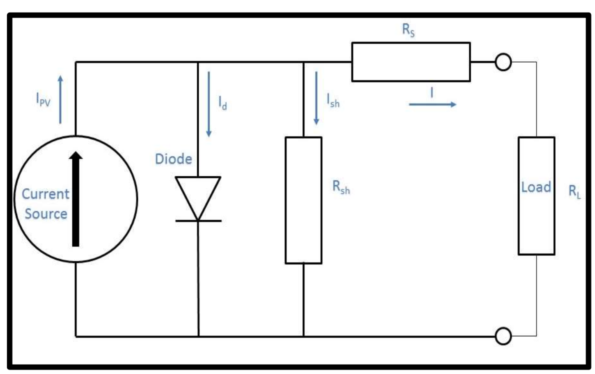

Fig. 1: Electrical circuit representing the PV cell

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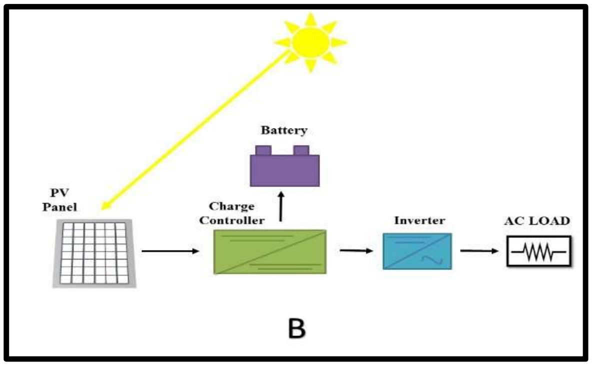

Fig. 2: Block diagram of a simple Stand-alone PV system

III. STAND-ALONE PV SYSTEM CONFIGURATION

The PV panels only produces DC voltage, while most home appliances are AC voltage operated, this means that an inverter is needed to turn the Direct Current (DC) into Alternating Current (AC). The PV panel has input solar energy during the day-time only, at night the PV cell does not produce power; this means that the systems needs storage system. Therefore, a battery is added to the system. The battery can charge during day-time and release during night-time. Applications such as illumination are only needed during night-time, as for day-time natural illumination using the sun could be applied. Other AC applications like ventilation can also be managed with this system. The charge controller provides the function of voltage regulation and protection for both the PV panel and the battery. Making sure that the battery does not overcharge or deep-discharge is very important to achieving the battery's artificial lifespan. This is the simplest configuration of stand-alone PV systems (as shown in figure 1). Other configuration may involve other devices coupled with the system to produce more electricity or maintain the voltage levels of the system, these systems are called "Hybrid" systems [26-33].

Gwani M. et al. (2015) [34] performed a study on the effect of Omn-Direction-Guide-Vane on the performance of a hybrid Wind-PV-Diesel-Battery stand-alone system. The study was conducted in Malaysia. The design was carried out using HOMER software and multiple cases were put forward for comparison. The authors concluded that the best outcome resulted from the system that uses (ODGV) which has a total net present cost of about 4,795 USD and a cost of energy of 0.021 USD/kWh. Other parameters were also studied. Using a wind-PV-diesel-battery system provides extra security to guarantee the reliability of the system, especially at peak load time.

Hidayat N. M., Kari M. N., and Mohd Arif M. J. (2014) [35], presented a study on finding the suitable State Of Charge (SOC) that is efficient to match with the solar potential of the system. The study was conducted in Ranau, Sabah, Malaysia. The source that operates (diesel/PV/battery) is set depending on Solar energy potential and SOC of the battery. Once battery runs-out, the diesel generator will begin to operate in order to meet the load demands. This shows the reliability of such systems. As the SOC begins to reach sufficient amount to supply the load, the diesel generator will stop and the battery will take over. Authors developed a load profile as explained above and studied the solar potential. Authors concluded that the most important element of such system is the battery and so studying the effect of solar irradiance data on the SOC is extremely important for battery management.

Al-Waeli A. H. and Alwaeli A. A (2016) [36], provided a design of a hybrid photovoltaic-diesel system for Baghdad, Iraq. The design was put forward for Al-Sadder city, which is a heavily populated city that suffers from the fluctuations of electricity and overall shortage. Grid electricity in this city is not a reliable source of energy and many generator stations have been constructed by the citizens in order to feed minimum loads. Authors stated that for reliability and safety measure a hybrid PV-Diesel system is the best solution for this city. The system is used generally when the gird-electricity goes out. Using HOMER software for the design, authors found a system to cover the entire city and has a net present cost of 1.11 million USD and a cost of energy of about 0.526 USD/kWh. Authors claim that using a hybrid system is helpful to reduce the Green House Gases (GHG) emissions.

IV. DESIGN METHODS

In order to build and install a PV system, many aspects are taking into consideration. The load to be supplied must be studied, in order to find the total Watts hour and the amount of time the load is used; this process is called load profiling. After creating the load profile a method to build the system is chosen. Some authors use intuitive equations and excel sheets in order to find, The size and number of PV panels, inverter, charge controllers and batteries. Other authors use numerical methods; such as HOMER software [37-51].

Izadyar N. et al. (2016) [52], performed an investigation on hybrid renewable energy potential for rural areas in Malaysia. The study was carried out at multiple locations. Authors used HOMER software in order to design the system in each of those locations. HOMER assisted the authors on finding more accurate results and faster. Authors concluded that Langkawi exhibits highest potential for hybrid solar/wind. As it achieved a total Net Present Cost (NPC) of 696,083 USD which is low in comparison to other locations. This study is achieved by comparing all of these system with the input being gathered from each location. HOMER software is crucial for this type of studies, which are important for investors in renewable energy systems.

Salam M. A. et al. (2013) [53] designed a standalone PV system to supply illumination of Renewable Energy Lab using HOMER software. Authors began by collecting the basic meteorological data for the locations (which is Sohar, Oman). Authors found a PV rated capacity of 700 Watts. The total NPC of the system is 6,233 USD and the cost of energy is 0.561 USD/kWh.

V. APPLICATIONS OF STAND-ALONE PV SYSTEMS

Various applications of stand-alone PV systems exist; as it can be used for water pumping applications, powering health clinics in rural areas, powering bus stops etc.

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Mhod Rosli M. A. et al. (2011) [54], Designed a stand-alone PV system to power two units of CFL lamps and LED display unit for a bus stop at UTM university in Malaysia. The authors chose a 15-degree tilt angle for the PV panels. Authors followed MS1837:2005 PV standard requirement to set important design specifications. Authors designed the load profile and suitable system components using intuitive equations displayed in tables. The system has 5 solar modules, 2 batteries, 3 charge controllers and an inverter. Authors installed and test the system and found that it works.

Mahmud A. (2011) [55], Designed and installed a hybrid PV system for rural school in Sabah, Malaysia. The authors chose a sample site to simulate the site (as it has similar load). The load profile was set and the rated load is 15.23 kW. A comparison between the expected load profile and actual load profile was conducted after installation. Using JSCADA system to record the load consumption helped in calculating the actual load profile. Authors designed a system that consists of 20 kWp PV module, 3500 Ah battery, bi-directional inverter, 27 KVA diesel generator. The elements with highest costs in this system are the batteries; as they form 44.56 % of the total cost.

Kazem H. A. et al. (2015) [56], presented an assessment of the technical and economic aspects of a photovoltaic powered water pumping system. Numerical and intuitive methods of design were used. Two tools for the numerical design of the system were used; HOMER software and a MATLAB developed tool named "REPS.OM". the optimum design is conducted to find a pumping system operated with PV system that has lowest cost. The system is installed in Sohar, Oman. Author concluded that numerical designs showed better results from intuitive ones. REPS.OM showed the best results as it has a Cost Of Energy (COE) of 0.180 USD/kWh as appose to 0.309 USD/kWh for HOMER. In addition, a design of a diesel generator has been conducted using HOMER software and it showed a COE of 0.790 USD/kWh which is over double the value of PV pumping systems' COE.

VI. APPLICATIONS OF A STAND-ALONE PV SYSTEM FOR A RURAL AREA IN MALAYSIA

The applications of stand-alone PV systems in the literature shows the broad range of loads a PV system can supply either on its own or combined with another source as hybrid. The literature also shows that stand-alone systems are suitable for rural areas in Malaysia generally. More research to prove this information must be conducted. The application of this study is to build a learning center that is powered by a PV system. The learning center is intended for a village in Sipitang, Sabah, Malaysia. Figure 3 shows the map of Malaysia (from google maps) and figure 4 shows the map of the targeted location (from google maps).

This project is helpful to the community of the village as it provides a space to learn and gain knowledge. Providing electricity to the learning center will play a major role in having an effective learning center; to have a comfortable venue with lighting, ventilation and to charge laptops (two laptops are donated to the learning center). Figure 5 shows the team leaders (authors) with the kids of the village -taking during the cite visit process.

Fig. 3: Map of Malaysia (google) – with the location pinned on it

Fig. 4: Map of Sipitang, Sabah (google) - with the location pinned on it.

Fig. 5: Authors with the kids of the village

VII. THE CONFIGURATION OF THE SYSTEM AND THE CAPITAL COSTS

The load profile of the learning center was found to be 1,880 watt-hours with a total connected wattage of 160 watts. The system designed consists of 4 PV arrays (180 watts), an inverter, a charge controller and 2 batteries (usable capacity of 250 Ah).

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As for the capital costs of the system:
Initial Costs: Cost of PV modules + cost of inverters + cost of charge controllers + cost of batteries + cost of wires of system.
CC = (360 USD/module × 4 modules) + (175 USD/controller × 1 controller) + (283 USD/inverter × 1 inverter) + (230 USD/battery × 2 battery) + System wiring price & installation (100USD) = **2,458 USD**.
As for the capital costs of the system:

Capital Cost Analysis: Cost of PV modules over system life cycle + cost of inverters over system life cycle + cost of charge controllers over system life cycle + cost of batteries over system life cycle + cost of wires of system life cycle

CC = (360 USD/module × 4 modules) + (175 USD/controller × 1 controller/ 6 years × 25 years) + (283 USD/inverter × 1 inverter/6 years × 25 years) + (230 USD/battery × 2 batteries/7 years × 25 years) + System wiring price & installation (180USD) = **5,171.2 USD**.

VIII. Conclusion

In conclusion, this paper presents an explanation and review of stand-alone PV systems; showing the main factors in the design process and the various applications for these systems. A number of research papers are discussed and conclusions are drawn from each study. The main conclusions of this paper is that stand-alone PV systems are an affective source of electricity for rural areas in Malaysia. Numerical and intuitive methods can be used to provide a design for such systems. A case study application of a stand-alone PV system for villager's in a rural area in Sipitang, Sabah, Malaysia. The system is composed of 4 PV panels, 2 batteries and an inverter and a charge controller. The system has an initial cost of 2,458 USD and a capital cost of 5,171.2 USD. The system is used to supply the load demands of a learning center that is installed for the youth of the village.

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