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Review on Optimised Configuration of Hybrid Solar-PV Diesel System for Off-grid Rural Electrification

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ABSTRACT

At present, solar energy is perceived to be one of the world's contributive energy sources. Holding characteristics such as inexhaustible and non-polluting, making it as the most prominent among renewable energy (RE) sources. The application of the solar energy has been well-developed and used for electricity generation through Photovoltaic (PV) as the harvesting medium. PV cells convert heat from the sun directly into the electricity to power up the electric loads. Solar PV system is commonly built in a rural area where it cannot be powered up by the utility grid due to location constrains. In order to avoid the electricity fluctuation because of unsteady amount of solar radiation, PV solar hybrid is the efficient solution for rural electrifications. This paper presents a review on optimised Hybrid Solar-PV Diesel system configurations installed and used to power up off grid settlements at various locations worldwide.

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1. INTRODUCTION

The reduction of fossil fuels resources has revived the interest in renewable energy resource utilization. So that, various activities have been conducted to identify reliable and economically feasible alternative sources of renewable energy. The choices include wave, wind, geothermal and solar energy. Among this energy types, solar energy is the popular source, which is widely used in heating and cooling applications. Solar energy is one of the renewable energy sources and this clean energy has potential to meet a significant amount of the world's energy demand. The evolution of renewable energy sources such as solar energy is a source of energy that provides benefits to the environment and clean energy. Solar energy converts to electric energy using photovoltaic (PV) technology [1]-[12]. Also, solar energy is widely used in solar thermal technology such as in solar drying systems [13]-[19], photovoltaic/thermal systems [20]-[27] and solar collector system [28]-[34].

As reported in the latest edition of World Energy Outlook 2017 by International Energy Agency (2017), in the new policies scenario, global energy demand needs to rise slowly than the past, but still expand by 30% in between today and 2040. According to Energy Access Outlook 2017, an estimation of 1.1 billion people – equivalent to 14% of the global population did not have access to electricity. Around 84% of those without electricity access reside in rural areas and more than 94% of those are from countries in Sub-Saharan African and developing Asia [35]. PV Solar energy technology is deemed as the best solutions in an effort to electrify off-grid rural areas. This is due to its ability to generate electricity; in fact many implementations have been successfully done worldwide. Solar-PV technology produces no GHG emissions without any noise produced during the operations making it the most environmentally friendly technology [36]. Common way used for rural electrification is by solar home system (SHS) which consisted of PV array, a charge controller and battery storage. This method is far economical than a regular approach using diesel generator as a source

for a single house [37]. However, in contrary with conventional energy sources, Renewable Energy sources are not capable to supply a uniform demand power because of the characteristic held by some sources that is vary in abundance with seasons and also can get affected by the geographical patterns at certain locations. However, this advantage of this system can be overcome by using solar energy in the form hybrid system [38]. The objective of this paper is to review on optimised Hybrid Solar-PV Diesel system configurations installed and used to power up off grid settlements at various locations worldwide.

2. HYBRID SOLAR SYSTEM

As known by the name, hybrid power system is an electrical power generation consisting of two or more energy sources. Hybrid system can be composed by two renewable sources (i.e solar energy, wind energy, hydro-electric, geothermal, etc) or a combination with conventional source. A common type is a PV solar diesel hybrid system. In providing a non-fluctuation power supply, hybrid systems often incorporate storage devices, such as batteries or fuel cells. Hybrid energy system is normally stationed to electrify remotes areas and can also be operated in parallel with grid power system if applicable [39]. Figure 1 shows the general architect of hybrid solar energy system, which is been implemented to meet electricity demand in many places. This hybrid system has become more competitive and practical approach for the electrification of remote areas with no grid-connected access [53]

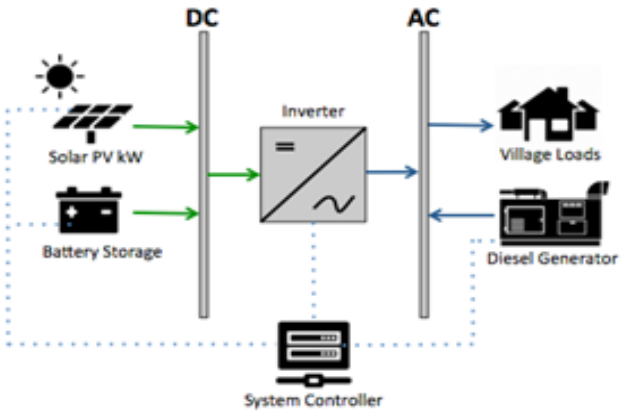

Figure 1. General architecture of hybrid solar energy system

Due to its complexity in configuration, hybrid solar system that consisted by two or more sources has to be designed to reduce the risk of failure in operation. Several studies have been conducted on a wide variety of methods used in designing, optimising, and operation controlling of hybrid energy system [40]. Some methods used are listed such as in Table 1. Table 1 shows studies and findings conducted with analyses and case study for some of the implemented system for the past decade ago.

Table 1. Methods used in Designing Hybrid Solar Energy System

Methods	Studied by;
Probabilistic	[41][42]
Analytical	[43][44][45]
Iterative	[46][47][48]
Hybrid Methods	[49][50]

Besides the conventional methods used, some efficient software have been developed in supporting the design process of hybrid system. They are such as in following:

a. HOMER
b. HYBRID2
c. HOGA

These softwares are commonly used to determine the feasibility of the designed system with some studies on the optimisation, cost effective and environmental analysis [51]. Rapid development and all of the

studies in every research of solar energy technology making this particular renewable energy to become more frequently used in hybrid systems compared with other renewable energy [52].

3. VARIETIES OF HYBRID SOLAR ENERGY

Hybrid solar system consisting of solar energy and other power sources have implemented all around the world. Some places are managed to be electrified by hybridisation of solar energy and other renewable sources like wind or hydro energy sources. However in certain places, a hybridisation of solar energy and conventional energy sources are more reliable and effective for rural electrifications. Although diesel generator is a common power source used for rural electrifications, but in the long term, it can become uneconomical, as the fluctuation in diesel price will anyhow affect it. Because of that, the approach of having solar energy hybridised with diesel generator is perceived as a better solution in providing the rural settlement uninterrupted power supply. In fact, gases emission from operating diesel generator can be reduced, as with available solar energy contribution, it is not in all time operation [54]. This subsection discusses the review of compatible and optimised of implemented hybrid solar system with diesel generator, which has been implemented over the last twelve years.

3.1. Hybrid Solar-PV Diesel System

In achieving a rural electrification in developing countries, renewable energy is playing a crucial role, especially solar energy. Hybrid solar system is a better approach compared to conventional, fossil fuel source on its own. This system has been world widely accepted, as it is not just protecting consumers from the unstable world's oil price, in fact the emissions of harmful greenhouse gases can also be reduced. In order to supply a 24 hours of uninterrupted power to the settlement, the hybrid solar-PV diesel energy system is one of the most reliable, cost –efficient, and environmentally friendly system that can serve remote areas, where the diesel generator acts as a backup solution in the absence of solar radiation or at night [55] [56].

In Malaysia, located 200 km from Miri, there is a hybrid solar-PV diesel system installed which can be used an example to understand the benefits of a hybrid solar-PV diesel system against a stand alone diesel generator system. It is also been verified by a software program that the hybrid solution was the optimal and most cost-effective approach. Simulated for 25yeras projections, a significantly lower COE and NPC were recorded. The simulation resulted that the annual emission is amounting at 432,259 kg from standalone diesel generator, while hybrid system produced emissions of 342,246 kg [54]. Table 2 shows summarize the prjets conducted on hybrid solar-PV diesel systems implemented with the economical outcome as reported by different researchers.

Table 2. Hybrid solar-PV Diesel Systems Implemented with the Economical Outcome

Project	Load Description	System Configuration			Economical Analysis			Ref.
		PV (kW)	Genset (kW)	Battery (kWh)	Type	COE $/kWh	NPC ($)	
Ulu Baram, Sarawak	40 houses, Load=421.94 MWh/yr	60	2 x 50	6V,1156Ah	Hybrid	0.796	4,292,632	[54]
					Diesel	0.875	4,722,083	
SMK Balleh, Sarawak	600 people + Boarding School	35	150	*NA*	Hybrid	0.1027	1,017,395	[57]
					Diesel	0.1029	1,020,184	
Kolkata, India	Technical Collage, Load=338.4MWh/yr	400	200	6V,1156 Ah	Hybrid	0.216	NA	[58]
					Diesel	0.717	NA	
Remote Settlements, Jordan	Houses with Laod 17.52MWh/yr	2	4	6V,1156Ah	Hybrid	0.297	66,227	[59]
					Diesel	0.324	72,068	
Dhahran, Saudi Arabia	Resindential Building, load 35.405 MWh/yr	4	10	6V,1156Ah	Hybrid	0.178	98,911	[60]
					Diesel	0.129	71,397	
Rawdat Ben Habbas Village, Saudi Arabia	Houses, Load=17,155MWh/yr	2000	1250	4V,1900Ah	Hybrid	0.219	NA	[61]
					Diesel	0.190	NA	

In most cases found in remote areas, where the diesel price is higher than in urban area, that is due to the additional transportation cost to bring in the fuel to the particular settlements. In other scenario, hybrid

solar energy does not provide the best economical system, but performed better in terms of technical and environmental aspects as well as lowest operating cost and also its ability to reduce the fossil fuel dependency [39].

4. CONCLUSIONS

This review of the last decades of reaserch, analysis and case studies confirms that the utility and cost-effectiveness of solar energy, particularly when it is been hybridized with diesel generator in the case of providing a 24 hour supply for rural electrification. Compared to a traditional stand alone diesel generator system, this study concluded that hybrid solar-PV diesel system is a cost competitive, eco-friendly, low maintenance and sort of alternative power solution to electrify off-grid rural locations.

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Ahmad Fudholi, Ph.D, M.Sc, S.Si obtained his S.Si (2002) in physics. He was born in 1980 in Pekanbaru, Indonesia. He has working experience about 4 years (2004-2008) as Head of Physics Department at Rab University Pekanbaru, Riau, Indonesia. A. Fudholi started his master course in Energy Technology (2005-2007) at Universiti Kebangsaan Malaysia (UKM). His M.Sc thesis was on Wind/PV Hybrid System and the Ph.D thesis was about the Finned Double-Pass Solar Collectors for Drying of Seaweed. His M.Sc and Ph.D thesis under supervisor by Prof Dato' Dr. Kamaruzzaman Sopian. After his master he became Research Assistant at UKM up to 2012. After his Ph.D (2012) in renewable energy, he became Postdoctoral in Solar Energy Research Institute (SERI) UKM up to 2013. He joined the SERI as a Lecture in 2014. More than USD 310,000 research grant (15 grant/ project) in 2014–2017 was involved. More than 25 M.Sc project supervised and completed. Until now, he managed to supervise 5 Ph.D (4 main supervisors and 1 Co. supervisor), 3 Master's student by research mode, and 5 Master's student by coursework mode, he was also as examiner (3 Ph.D and 1 M.Sc). His current research focuses on renewable energy, especially solar energy technology, micropower system, solar drying systems, and advanced solar thermal systems (solar assisted drying, solar heat pump, PVT systems). He has published more than 120 peer-reviewed papers, which 25 papers in ISI index (20 Q1, impact factor more than 3) and more than 60 papers in Scopus index, 16 more currently accepted manuscript, 20 more currently under review, and 2 book chapters. Addition, he has published more than 70 papers in international conferences. His total citations of 810 and h-index of 14 in Scopus (Author ID: 57195432490). His total citations of 1387 and h-index of 20 in google scholar. He is appointed as reviewer of high impact (Q1) journal such as Renewable and Sustainable Energy Reviews, Energy Conversion and Management, Applied Energy, Energy and Buildings, Applied Thermal Engineering, Energy, Industrial Crops and Products, etc. He is appointed as reviewer of reputation journals such as Drying Technology, International Journal of Green Energy, Biosystem Engineering, Journal of Sustainability Science and Management, Journal of Energy Efficiency, Sains Malaysiana, Jurnal Teknologi etc. He is also appointed as editor journals. He has received several awards such as Gold Medal Award at the International Ibn Al-Haytham's Al-Manazir Innovation and Invention Exhibition 2011, Silver Medal Award at

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Mr Stephen Phillips has an extensive background in the development and commercialisation of renewable energy technologies, both in Australia and internationally. He has lead several companies in accessing a range of international markets including India, Philippines, Malaysia, China, Taiwan, Indonesia and the USA. Stephen completed his Bachelor of Science at Murdoch University, Perth, Australia, with a Master of Electrical Engineering from Curtin University, Perth, Australia. After holding the position of Principal Investigator from 1986-1989 at Australia's Murdoch University Energy Research Institute. His research at Sandia National Laboratories, Albuquerque, USA awarded him with a Churchill Fellowship in 1987 for Solar Energy Research and since this date he has had over 50 papers published in the field of renewable systems technology. Stephen has also been a keynote speaker at APEC conferences in Indonesia as well as the Japanese Government Institute of Science & Technology, Tokyo. Mr Phillips also operates as a consultant specialising in photovoltaic technologies as well as renewable energy for the Australian Government, the Queensland Premier's Department and Murdoch University.

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