FRAMEWORK DESIGN OF AN OFF-GRID REMOTE 3-BEDROOM HOUSE USING SOLAR DC POWER SYSTEM

by

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LIST OF ABBREVIATIONS

AC	Alternating current
BOS	Balanced of system
CES	Centralized electrification system
DC	Direct current
DLs	Distribution Licensees
DOD	Depth of discharge
FiAHs	Feed-in Approval Holders
FiT	Feed-in Tariff
GCPV	Grid-connected photovoltaic
GHG	Greenhouse gases
HOMER	Hybrid Optimization of Multiple Energy Resources
IES	Individual electrification system
KeTTHA	Ministry of Energy, Green Technology and Water
kWh	kilowatt-hour
kWp	Kilowatt peak
LCOE	Levelized Cost of Energy
LED	Light-emitting diode
LSS	Large Scale Solar
MPPT	Maximum power point tracking
MW	Megawatt
NEM	Net Energy Metering
NPC	Net present cost
PR	Performance ratio
PV	Photovoltaic
SAPV	Stand-alone photovoltaic
SEDA	Sustainable Energy Development Authority of Malaysia
SELCO	Self-consumption
SOC	State of charge
SY	Specific yield
TNB	Tenaga Nasional Berhad

LIST OF SYMBOLS

C_{ah_bat}	Battery bank capacity
C_{ah_req}	Charge storage capacity required
C_{bat}	Battery capacity
DOD_{max}	Maximum depth of discharge allowed
E_{ideal}	Ideal energy output from PV array at STC
E_{req}	Energy required
E_{sys}	Energy generated from PV system
f_{age}	PV module age derating factor
f_{dirt}	Dirt derating factor
f_{mm}	PV module mismatch power tolerance
f_{temp_avg}	Temperature derating factor
I_{mpp}	Current at P_{max}
I_{sc}	Short-circuit current
$k_{derating}$	Derating factor
$k_{oversize}$	Oversize factor
$k_{storage}$	Battery efficiency
P_{array_stc}	Power rating of the PV array at STC
P_{max}	Maximum output power
P_{mp_stc}	Power rating of a PV module at STC
PSH	Peak Sun Hour
SY	Specific yield of the PV system
T_{aut}	Number of autonomy day
T_{cell_avg}	Average daily maximum temperature
T_{stc}	Temperature at STC
V_{bat_nom}	Nominal voltage of battery
V_{mpp}	Voltage at P_{max}
V_{oc}	Open-circuit voltage
V_{sys}	System voltage
η_{cable}	Cable efficiency
$\eta c_{onverter}$	Electrical converter efficiency
η_{sub_system}	Conversion efficiency
STC	Standard Test Condition

Reka Bentuk Rangka Kerja Rumah 3-Bilik Tidur Luar Grid Menggunakan Sistem Kuasa AT Suria

ABSTRAK

Penggunaan sistem kuasa tenaga boleh baharu kini semakin popular dengan peningkatan permintaan terhadap tenaga dan kebimbangan terhadap pelepasan gas karbon dioksida ke alam sekitar yang akan menyebabkan pemanasan global. Pada masa ini terdapat minat yang semakin meningkat untuk menggunakan AT sebagai cara menghantar kuasa kepada beban kerana banyak kelebihannya berbanding AU. Namun begitu, tinjauan literatur mendedahkan bahawa terdapat pelbagai pendekatan reka bentuk dan andaian yang digunakan dalam pelbagai kajian penyelidikan, menghasilkan kebolehubahan yang ketara. Di samping itu, terdapat pelbagai pendekatan telah dikenal pasti dalam analisis ekonomi. Oleh itu, adalah penting untuk membangunkan satu set prinsip dan prosedur reka bentuk yang seragam, bersama-sama dengan struktur ekonomi, untuk aspek reka bentuk sistem AT. Oleh itu, objektif kajian ini adalah untuk menambah baik reka bentuk rangka kerja rumah sistem PV solar luar grid menggunakan sistem kuasa suria AT untuk mencapai pecahan tenaga boleh diperbaharui 100% dan memenuhi permintaan beban tahunan. Beban akan menjadi rumah kediaman 3-bilik tidur yang digunakan dalam jalur penggunaan tenaga terkecil iaitu 200 kWj sebulan. Proses yang terlibat ialah pemilihan tapak projek, pemprofilan beban kediaman, pengiraan reka bentuk, pengesahan sistem reka bentuk melalui simulasi PVsyst dan Homer untuk prestasi teknikal dan ekonomi dan akhir sekali pembangunan prototaip. Proses rekabentuk untuk aspek teknikal telah dilakukan dengan menggunakan pengiraan rekabentuk, yang kemudiannya disahkan melalui penggunaan simulasi PVsyst. Kemudian, analisa tekno-ekonomi sistem kuasa suria PV telah dijalankan menggunakan perisian Homer Pro. Akhir sekali, prosedur merekabentuk dan membangunkan prototaip yang dikenali sebagai modul kuasa AT untuk tujuan pengagihan tenaga kepada bangunan kediaman berkuasa AT sepenuhnya. Berdasarkan keputusan yang diperoleh, kedua-dua kaedah yang merupakan pengiraan rekabentuk dan simulasi PVsyst mempamerkan keputusan yang hampir sama justeru boleh disimpulkan bahawa kedua-dua metodologi boleh dilaksanakan dalam menentukan konfigurasi yang paling berkesan untuk sistem kuasa suria PV. Untuk analisa tekno-ekonomi yang menggunakan perisian Homer Pro, sistem suria PV AT menunjukkan kos permulaan dan LCOE yang lebih rendah berbanding sistem solar PV AU. Walau bagaimanapun, dari segi nilai LCOE, adalah lebih tinggi jika dibandingkan dengan kadar tarif grid kepada pengguna yang menggunakan 200 kWj. Selain itu, modul kuasa AT telah berjaya direkabentuk dan dibangunkan untuk pengagihan kuasa AT kepada kediaman AT sepenuhnya. Prototaip ini boleh membekalkan tenaga elektrik kepada kedua-dua beban kuasa tinggi dan kuasa rendah menggunakan kedua-dua keluaran 48 V dc dan 12 V dc dengan kuasa maksimum hampir 1,600 W. Akhir sekali, dari segi persekitaran, persediaan rekabentuk ini dijangka dapat memberi manfaat kepada pengguna kediaman dalam mengurangkan penggunaan elektrik utiliti sehingga 2,434 kWj setahun yang bersamaan dengan hampir 1.7 tan pengelakan pelepasan karbon ke alam sekitar setiap tahun.

Framework Design of an Off-grid Remote 3-Bedroom House using Solar DC Power System

ABSTRACT

The utilization of renewable energy power systems is currently gaining widespread popularity with the increase of energy demand and concerns on the carbon dioxide emission to the environment that will cause global warming. Malaysia has move forward by promoting used of renewable energy such as solar PV to the public where it generated locally at a distribution voltage level. Presently there is growing interest in employing DC as a means of delivering power to the load due to its numerous advantages in comparison to AC. Furthermore, since the electricity generated by a solar PV system is in DC, the totally DC system will contribute to the overall simplicity of the system design. Nevertheless, literature reviews reveal that there is a broad variety of design approaches and assumptions employed in various research studies, resulting in significant variability. In addition, numerous approaches have been identified in economic analysis. Therefore, it is crucial to develop a uniform set of design principles and procedures, together with an economic structure, for the design aspects of DC system. Therefore, the objective of this study is to improve the framework design of an off-grid solar PV system house using solar DC power system to achieve the 100% renewable energy fraction and fulfilling the annual load demand. The load will be a 3-bedroom residential house that consumed within the smallest energy consumption band which is 200 kWh per month. The processes involved are project site selection, residential load profiling, design calculation, verification of the designed system through PVsyst and Homer simulation for technical and economic performance and lastly prototype development. The design process for a technical aspect has been performed by deploying design calculations, which were subsequently validated through the use of PVsyst simulation. Then, a techno-economic analysis of a solar PV power system was conducted utilizing the Homer Pro software. Finally, the procedure of designing and developing a prototype known as the DC power module for the purpose of distributing energy to a fully DC-powered residential building. Based on the results obtained, both methods which are design calculations and have PVsyst simulation exhibited nearly identical results hence it can be concluded that both methodologies are feasible in ascertaining the most effective configuration for a solar PV power system. For the techno-economic analysis utilizing Homer Pro software, the solar PV DC system demonstrates lower initial cost and LCOE compared to the solar PV AC system. However, in terms of LCOE value, is comparatively higher when compared with the grid tariff rate to users consuming 200 kWh. In addition, DC power module has been successfully designed and developed for distribution of DC power to a fully DC residential. This prototype can provide electricity to both high-power and low-power loads using both of its 48 V DC and 12 V DC output with the maximum power nearly 1,600 W. Lastly, in terms of environment, this design set-up is expected to benefit the residential consumers in reducing utility electricity consumption up to 2,434 kWh per year which is equivalent to almost 1.7 tons of carbon emissions avoidance into the environment annually.

CHAPTER 1 : INTRODUCTION

1.1 Background of the study

Energy plays a vital role in our everyday existence. It is imperative to not only fulfil the requirements of social and economic progress, but also enhance human health and well-being. The escalating pattern of energy consumption is directly linked to the concurrent rise in greenhouse gas (GHG) emissions. This can be mostly attributed to the overwhelming reliance on fossil fuels for the majority of energy provision. (Abd Wahid et al., 2016). Malaysia still depending on the fossil-fuelled based energy for electricity generation. Based on statistic, from total 35,037 MW of installed capacity available for electricity generation in 2020, 37.3% is from natural gas while 37.9% from coal and diesel 1.5%. Hydroelectric power, as the primary source of renewable energy in Malaysia, accounts for a modest 23% of the total energy contribution from national generation mix while others only 0.1%. Figure 1.1 shows the installed capacity by fuel type in Malaysia in 2018.

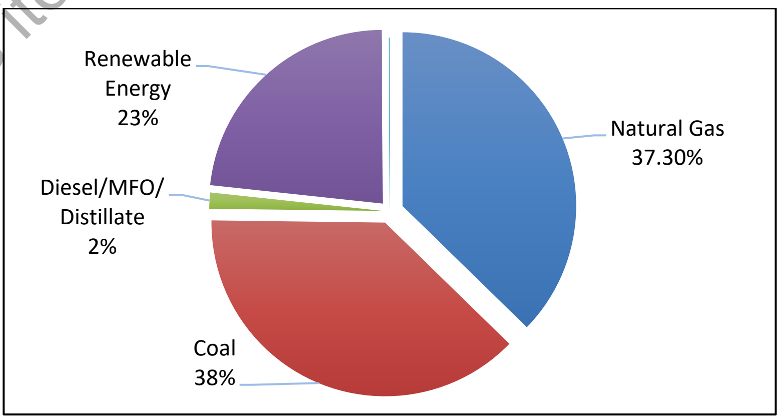

Figure 1.1 Installed capacity by fuel type in Malaysia in 2020 (Energy Commission, 2020b)

The volatility of fuel prices for power generation is a primary be concerned for customers due to its impact on energy tariffs. The last time electricity tariff revision was conducted in 2014 where the average electricity tariff has increased from 33.54 sen per kWh to 38.53 sen per kWh. With the exception of two domestic customer groups, all categories have demonstrated an increase in tariff prices as compared to the prior tariff. The aforementioned groups consist of individuals who have a monthly electricity consumption of up to 200 kWh, as well as those whose electricity usage falls between the range of 201 to 300 kWh per month. Both groups collectively account for the majority of domestic users, with over 4.56 million customers. Nevertheless, given the unpredictable nature of fuel costs, it cannot be assured that the tariff for these two categories would remain unchanged. Table 1.1 shows the electricity tariff revision in 2014 for domestic customers in Peninsular of Malaysia (KeTTHA, 2013).

Table 1.1 : Electricity tariff for domestic customer in Peninsular of Malaysia (Revision 2014)

Consumption Band (kWh)	Tariff Rate (sen / kWh)	Number of customers (Percentage)
0 – 200	21.80	50.37 %
201 – 300	33.40	20.30 %
301 – 600	51.60	21.54 %
601 – 900	54.60	7.79 %
901 and above	57.10	

Malaysia is prioritising solar energy as its main renewable source. By 2030, the country's objective is to establish itself as a central location for the manufacturing of solar photovoltaic (PV) technology. The National Renewable Energy Policy and Action Plan (NREPAP) aims to achieve substantial expansion in solar photovoltaic (PV) installations. In 2018, Malaysia's energy composition was predominantly composed of fossil fuels, with gas accounting for 35% and coal for 57%. Renewable energy (RE) sources currently have a very modest portion of the energy market, but it is necessary to grow their proportion in order to meet future energy objectives (Vaka et al., 2020). Malaysia is currently using hydropower, solar energy, and bioenergy (including biomass, biodiesel, and biogas) as its primary renewable energy sources. The objective is to raise the proportion of renewable energy to 31% by 2025 and 40% by 2035.

Malaysia's reliance on fossil fuels makes energy security a significant concern. The government has implemented many measures to increase the proportion of renewable energy in the energy mix, including as the National Energy Policy, Four Fuel Diversification Policy, and the Eleventh Malaysia Plan. (Ibrahim et al., 2022). Malaysia has made a firm commitment to decrease its greenhouse gas emissions by 45% by the year 2030 as part of its commitments under the Paris Agreement. The primary objective of the National Energy Policy (NEP 2022) is to enhance the utilisation of renewable energy sources and enhance the efficiency of energy storage systems (J. Y. Lee et al., 2023).

The energy sector in Malaysia experienced a substantial impact from the COVID-19 epidemic in 2020, resulting in a decrease in the manufacture and installation of solar PV modules. The government implemented stimulus measures in order to guarantee a viable and enduring energy future. In order to uphold the objectives of the Paris Agreement, Malaysia must modify its policies and strategies to address the challenges posed by the epidemic. The primary objective continues to be the expansion of renewable energy capacity while also assuring energy security (Koerner et al., 2022). Numbers of studies have highlighted the significance of renewable energy in mitigating greenhouse gas (GHG) emissions and tackling the challenges posed by climate change (Khan et al., 2022). These studies collectively emphasize the benefits of integrating renewable energy systems for reducing greenhouse gas emissions and addressing climate change. They also highlight the economic feasibility and environmental advantages of various hybrid energy systems in different geographical and climatic conditions (B. K. Das et al., 2021). The crucial role of renewable energy sources, which include solar PV, for dealing with climate change by decreasing carbon emissions and encouraging sustainable energy habits, has been highlighted (Khezri et al., 2022). Furthermore, the utilisation of building-integrated photovoltaics (BIPV) and other renewable energy technologies has the capacity to significantly decrease energy consumption and carbon footprint within the building industry (Panicker et al., 2023).

Malaysia has made significant progress in marketing the use of renewable energy sources to the public, with a focus on locally generated power at the distribution voltage level. The government has introduced a number of policies for the past 30 years, to accelerate renewable energy penetration. Prior to 1980, oil was the primary source of electricity. In 1981, Malaysia introduced the Four Fuel Diversification Policy, highlighting hydro as one of the contributors to the nation's energy mix. However large-scale hydro power plants only managed to supply around 10% of the electricity requirement in Malaysia, while another 90% of the supply was still dominated by other non-renewable sources such as coal and natural gas. In 2001, the Fifth Fuel Policy was introduced which identified the potential in biomass, biogas, small hydro and solar as sources of electricity generation. Subsequently, the Renewable Energy Act has been gazette in 2011, which aimed at achieving 5.5% of the country's electricity generation from the renewable energy sources by the end of 2015. The Feed-in Tariff (FiT) scheme has been introduced where the RE producers will be paid at a fixed rate or tariff for each unit of electricity exported to the grid for a period up to 21 years. The FiT rate will be based on several factors such as:

i) Type of renewable resource used where each resource will have set of tariffs.

ii) The size of installed capacity where larger the capacity size, the tariff will be lower.

iii) Meeting any criteria entitling to additional bonus rates such as locally made equipment.

iv) The year of FiT application been approved where the rate is gradually lowered every year in line with the reducing cost of the technology.

There are four RE resources listed under the FiT scheme which are biomass, biogas, small hydropower and solar photovoltaic (PV). The selection of these four candidates is based on their demonstrated technological effectiveness and their potential to thrive within the specific environmental conditions present in Malaysia. According to SEDA Malaysia portal, 614.72 MW of renewable energy capacities are in operation under FiT scheme have achieved the FiT Commencement Date between 2012 until 2020. Figure 1.2 shows the percentage of each renewable energy technology capacity that has achieved the FiT Commencement Date between 2012 until 2020.

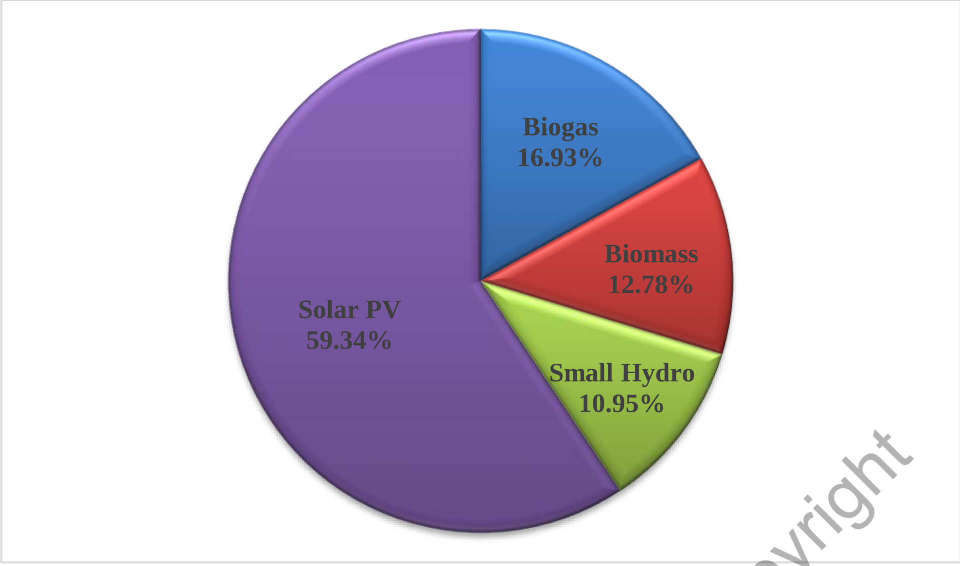

Figure 1.2 Percentage of renewable energy capacity in operation under FiT (2012-2020)

The term "biomass" refers to organic matter derived from plants, trees, and crops. Example of biomass sources are residues from agricultural crop, waste from livestock operations, wood, and municipal solid waste. The generation of electrical power can be achieved by the combustion of biomass, utilizing technology comparable to that applied in fossil fuel systems for the production of heat and electricity. There are two categories of biomass under FiT which are biomass and biomass (municipal solid waste) and also based on capacity size.

Biogas is a gas produced by the anaerobic digestion or fermentation of organic matter under anaerobic conditions such as manure, sewage sludge, municipal solid waste, and biodegradable waste. The utilization of biogas technology enables the conversion of organic waste materials into a viable source of energy. The liberation of energy enables the utilization of biogas as a viable fuel source in a gas engine, facilitating the conversion