Design and Simulation of Solar Powered Mobile Battery Swap ChargingStation Using Pvsyst Software: A Case Study

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ABSTRACT

The adoption of electric motorcycles (EM) in Indonesia is still relatively low because of limited charging facilities. The concept of mobile battery swap charging stations (MBSCS) can be developed to accelerate the amount of infrastructure of MBSCS and increase community awareness about EM adoption in Indonesia. This study acts as part of MBSCS technical development. This study aims to analyze the stand-alone solar power generator operation used in solar-powered MBSCS and its performance ratio. PVSyst software was used in this study to simulate the operational and performance analysis of the design. This study shows the best system configuration to be used in MBSCS and its performance ratio. This study shows that the chosen system variant has an average annual energy requirement of 12,352 kWh, with energy supplied to users of 11,129 kWh per year, 1225.5 kWh less than the required load. This study also shows that the best system variants chosen have an average annual performance ratio of 75.5%. The findings of this study serve as a technical consideration in building the MBSCS and also demonstrate the potential of mobile solar power generators.

Keywords:

1. Introduction

The adoption of electric motorcycles in Indonesia is still relatively low. Eventhough people have a high interest and they consider about the advantages of electric vehicles such as electric vehicles are more environmentally friendly, energy costs are cheaper and relatively do not require intensive maintenance, howeverthe adoption of electric vehicle is considered low. Some of the reasons for the low adoption of electric motorcycles are short mileage, the long battery charging time and limited spread of battery charging station facilities [1]–[6]. To overcome the long battery charging time, researchers in Indonesia have developed electric motorcycles that use a battery swap system as a battery charging method [1]. The battery swap system allows electric motorcyclesto charge the battery by exchanging an empty battery with a charged battery [1], [3], [4], [6], [7]. The battery swapsystem is considered a simple, fast, and highly efficient battery charging system solution [1], [8].

The concept of mobile battery swap charging station (MBSCS) for electric motorcycles is developed not only for accelerating the amount of infrastructure of MBSCS, but also is used to increase awareness to the community to increase the adoption and diffusion of electric motorcycles in Indonesia. MBSCS can be used as a tool for marketing campaign and socialisation [6]. MBSCS is considered simple, flexible, and required low-cost investment in terms of the manufacturing process. The existence of MBSCS is not intended to replace Fixed Battery Charging Station (FBCS) but can benefit as an alternative to accelerating the fulfilment of infrastructure that complements the existence of FBCS [9], [10]. In the areas where electric charging infrastructure is still not available, the existence of MBSCS can temporarily meet the demand for electric charging stations, until the FBCS network is available in the area.

This study aims to develop an initial design of a solar powered MBSCS. Therefore, to develop MBSCS, this paper aims to provide the prototype design of MBSCS, MBSCS operational simulation, and technical indicator to assess the MBSCS system. This paper is organized as follows: after the introduction section, the second section provides the research methodology. The third section present the simulation results of nine systemvariant of MBSCS operational, best system variant according to technical assessment, and detailed results of the best system variant in this study. Finally, the fourth section give the conclusions of the study.

2. Methodology

This study uses the simulation through PVSyst software with the processes shown in Figure 1. Then, its results are assessed using the technical assessment indicator shown in Table 1. The best system configuration isdetermined by looking the system variant with the most first ranking in every indicator.

2.1 Simulation Process

Simulation in this study is using PVSyst software. PVSyst is a software for simulate the operational of solar power plant system [11]. This software helps in designing the system configuration and to help estimating the generated energy from the solar power plant design through simulation. The simulation results are based in the system configuration which further depends on geographical location of the solar power plant system. Simulation results may include several simulation variables, for this study purposes, the results variables are according to technical indicator shown in point 2.2. Simulation process in PVSyst is carried out as shown in Figure 1.

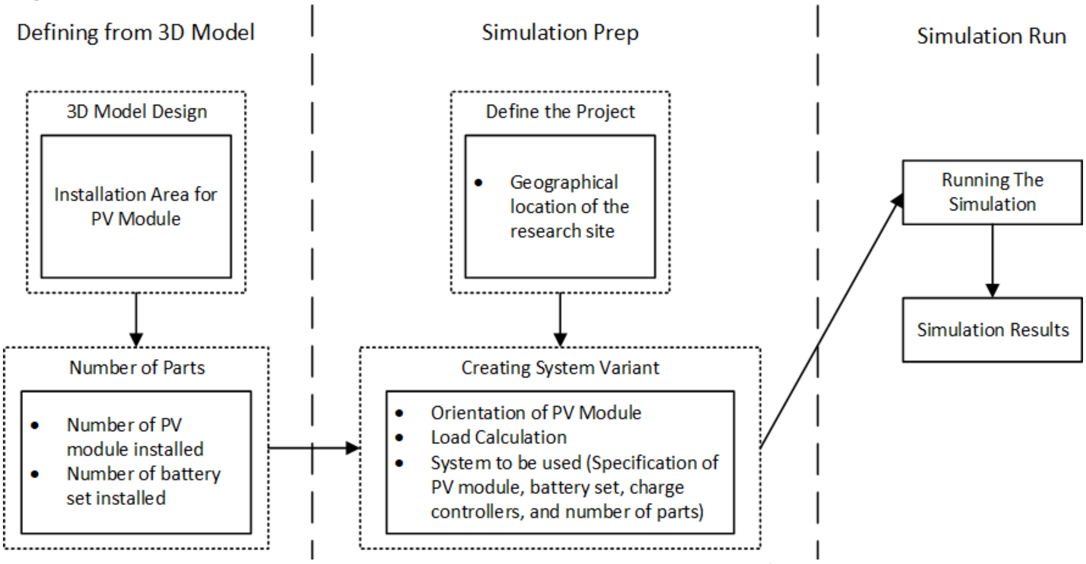

Figure 1 Simulation Process Using PVSyst Software

2.1.1 Defining from 3D Model

Three-dimensional (3D) model design of MBSCS is present and from it the installation areaof PV module can be obtained. Next, the calculation of the number of PV modules and battery sets to be installed is conducted. The calculation of the number of installed PV is influenced by the installation area obtained from the 3D model and the dimensions of the PV module. Meanwhile, the number of battery sets installed is influenced by the daily energy required and battery set capacity.

2.1.2 Simulation Prep

Geographical location of the research site is defined by the researcher and becomes input tosimulation software. Geographical location is important because the result will be depends largely on it. Next, the researcher needs to create the system variant to be tested in simulation. There are three main parameters to be defined by the researcher, namely orientation of PV module, load calculation, and system that will be uses in the simulation.

2.1.3 Simulation Run

Simulation generates a report of the results with list of tables and/or graphs. Researcher cananalyze the results according to the aims of the study. The aims of present study are as follows:

- To assess the solar power potential at research site

- To assess the technicality of the off-grid solar power plant system used in MBSCS
- To determine number of PV module and battery sets should be installed in MBSCS
- To determine the performance ratio of the off-grid solar power plant system used inMBSCS

2.2 Technical Assessment Indicator

Technical indicator is used to assess the simulation results and find the best system variant among others variant. Technical indicator used in this study follows from previous study as shown in Table 1 [3]. The results of assessment then used to look the simulation results of the best system variant in more detailed manner.

Table 1 Technical Indicator Used for Assessment

Indicators	Definition	Preferable Condition
E_Avail	Electrical energy available from the PV panel	Expected to be bigger
E_Unused	Unused electrical energy (because the storage battery is full)	Expected to be lower
E_Miss	Unfulfilled electrical energy needs	Expected to be lower
E_User	The electrical energy distributed to the user's system	Expected to be bigger
SolFrac	The percentage of electrical energy that meets energy needs	Expected to be bigger
PR	The percentage of average annual performance ratio	Expected to be bigger

3. Mobile Battery Swap Charging Station Design (MBSCS)

MBSCS concept was introduce by Rahmania *et al.* as a battery charging station that can go mobile [4]. This concept was later realized as a three-dimensional model in Chaniago's research under the name of Mobile Battery Swap Charging Station, known as MBSCS [3]. MBSCS is a mobile charging station that uses a battery swap system with an electricity source from an off-grid solar power plant. MBSCS technology is currently still in the development and prototyping stage. Therefore, as part of MBSCS development, it is necessary to conduct a simulation of the MBSCS operational to test the technicality of the design.

3.1 MBSCS Three-Dimensional Design Prototype

MBSCS three-dimensional (3D) design is shown in Figure 2. This research focuses on the design and simulation of a solar power plant that is used as a source of electrical energy at solar-powered MBSCS.From Figure 2, the PV module can be seen by blue color.

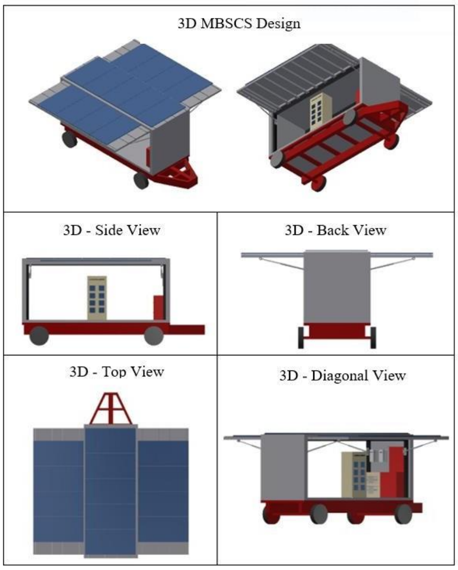

Figure 2 MBSCS Three-Dimensional Design

From MBSCS design prototype, we can know about the overall dimension of the design. PV module will be installed on three sides of MBSCS design, namely upper, right, and left side. The installation areafor PV module in this study follows the dimension shown in Table 2.

Table 2 PV Module Installation Area

Container Side	Dimension (mm)	Area (mm^2)
Upper side	6060×2440	14786400
Right side	5710×2000	11420000
Left side	5710×2000	11420000
Total PV Module Installation Area		37626400

3.2 Number of PV Module

The number of PV module calculation are carried out to determine the number of PV panels used and the estimated electrical power generated. This calculation has limitations, namely the number of PV module used are optimized to installation area according to upper, right, and left side of MBSCS container. The number of PV module (NPV) calculated using formula shown in Equation 1.

$$N_{PV} = \sum \frac{installation\ area\ for\ every\ side\ of\ container}{PV\ module\ area} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . (1)$$

Calculation results for NPV is shown in Table 3. installation area for every side of corner in the formula refer to side area of MBSCS container as shown in Table X. PV module area in the formula refer to dimension of every PV module variant as shown in Table 6. The result shows that every system variant with JKM415M-54HL4 is 17 units, JKM490M-7RL3 is 16 units, and JKM550M-72HL4 is 13 units.

Table 3 Number of PV Module Used

PV Module Variant	JKM415M-54HL4	JKM490M-7RL3	JKM550M-72HL4
Upper side of container	7	6	5
Right side of container	5	5	4
Left side of container	5	5	4
Total number of PV module	17 units	16 units	13 units

3.3 Number of Battery Set

The number of batteries for MBSCS optimizes the capacity of battery set used. The number of batteries set used in MBSCS is affected by the electrical power required for operational purposes and the battery set capacity. The number of battery set (NBatt) calculated using formula shown in Equation 2.

$$N_{Batt} = \frac{Daily\ energy\ required}{Battery\ set\ capacity} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . (2)$$

Calculation results for N_{Batt} is shown in Table 4. Daily energy required in the formula refer to load calculation as shown in Table 5. Battery set capacity in the formula refer to battery set capacity per one battery as shown in Table 7. The result shows that every system variant with battery set capacity of 100 Ah is 7 units, battery set capacity of 150 Ah is 5 units, and battery set capacity of 200 Ah is 4 units.

Table 4 Number of Battery Set Used

Battery Set Variant	Calculation Results	Quantity Rounding
FERPHOS 18650 48V 100Ah	7.05	7 units
FERPHOS 18650 48V 150Ah	4.70	5 units
FERPHOS 18650 48V 200Ah	3.53	4 units

4. Stand-alone PV System Design for MBSCS

Stand-alone PV system or can be referred to as an off-grid system is a PV system that is not connected to any electricity grid. This system is commonly used for areas that are isolated or far from large power grids. PV modules are used to generate electrical energy which is then stored in a battery set. Battery set is used for energy storage. The energy generated by the PV modules is channeled through the charge controller which functions to charge the battery and prevent overcharging [12]. Inverters are also used in this system for the need to convert the DC current generated by the PV module into AC current so that it can be used for AC appliances. [12]. In this study, the PV module is mounted on the top of the MBSCS design as shown in Figure 2.

4.1 Load Calculation

The estimated daily load consumption of MBSCS design as listed in Table 5 below.

Table 5 Daily load consumption for MBSCS

Appliances	Power (W)	Quantity	Daily Use (hour/day)	Daily Energy Required (Wh/day)
Lamp	20	1	12	240
EV swap battery	300	8	12	28800
Standby consumer	200	1	24	4800
Total daily energy required				33840 Wh/day
Total monthly energy required				1015.2 kWh/month
Total yearly energy required				12352 kWh/year

4.2 Specification of PV Module

This study tested three variants of the PV module with the detailed specification shown in Table 6 below.

Table 6 Specification details of PV modules

Model	JKM415M-54HL4	JKM490M-7RL3	JKM550M-72HL4
Manufacturer	Jinko Solar	Jinko Solar	Jinko Solar
Cell type	P-type mono	P-type mono	P-type mono
Dimension	1722x1134x30 mm	2182x1029x35mm	2274x1134x35 mm
Total PV module quantity	17	16	13
Module power	415 Wp	490 Wp	550 Wp
Max. power voltage (Vmpp)	28.88 V	43.68 V	40.90 V
Open-circuit voltage (Voc)	37.31 V	52.54 V	49.62 V
Max. current (Impp)	13.48 A	11.22 A	13.45 A
Short-circuit current (Isc)	14.01 A	12.04 A	14.03 A
Module efficiency STC	21.25%	21.82%	21.33%

4.3 Specification of Battery Set

This study tested three variants of the battery set with the detailed specification shown in Table 7 below.

Table 7 Specification details of battery set

Model	FERPHOS 18650 48V 100Ah	FERPHOS 18650 48V 150Ah	FERPHOS 18650 48V 200Ah
Manufacturer	Batex	Batex	Batex
Cell materials	$LiFePo_4$	$LiFePo_4$	$LiFePo_4$
Battery in series	15	15	15
Battery in parallel	56	84	112
Total battery pack quantity	7	5	4
Battery pack voltage	48 V	48 V	48 V
Battery capacity (per 1 battery)	100 Ah	150 Ah	200 Ah
Global capacity	700 Ah	750 Ah	800 Ah
Stored energy (80% DOD)	30.5 kWh	32.7 kWh	34.8 kWh
Total weight	277 kg	296 kg	316 kg
Number of cycles at 80% DOD	800	800	800
Total stored energy during the battery life	21.97 MWh	23.54 MWh	25.11 MWh

4.4 Specification of Charge Controllers

Charge controllers used in this study is universal controller MPPT Converter of 1000 W and 48 Vhaving maximum charging and discharging current of 152 A to 55 A.

4.5 Orientation of PV Module

This study will simulate PV module structure with fixed tilted plane of 0^0 and plane orientation azimuth 0^0 (horizontal fixed plane) as shown in Figure 3. Optimization with respect to yearly irradiation yield resulted in loss with respect to optimum is -2.1% and energy on collector plane is 1881 kWh/m^2 as shown in Figure 3.

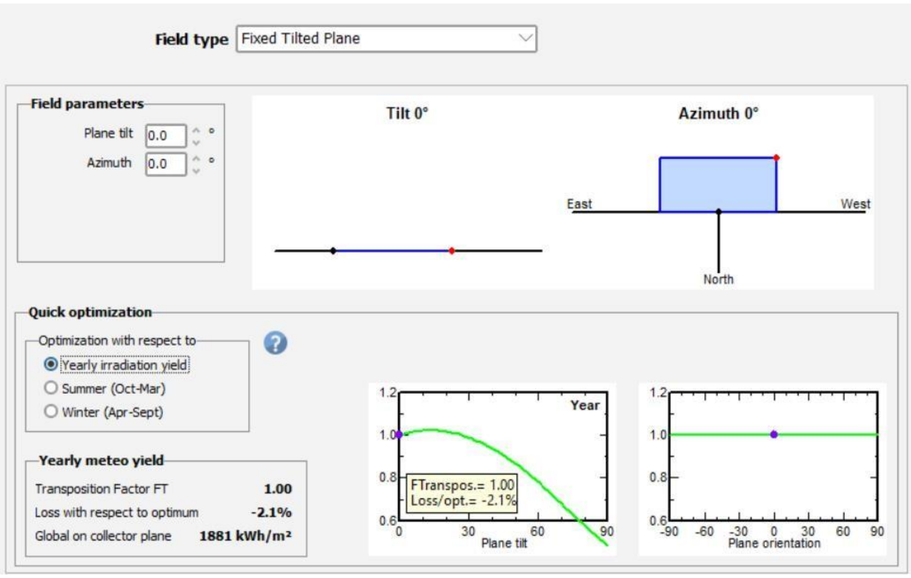

Figure 3 PV module orientation

4.6 System Variant to be Simulated

This study will simulate several variants of the system while other main parameters such orientation and load are considered constant. Variant of the system will simulate different PV module and battery set,while using same charge controller for all variant. Specification detail of PV module used in this study asshown in Table 6. Specification detail of battery set used in this study as shown in Table 7. Specification of charge controller used in this study as shown in point 3.4. Variant of PV module and battery set as shownin Table 8.

Table 8 System Variant to be Simulated

System Variant	PV Panel Variant	Quantity	Battery Set Variant	Quantity
System variant 1	415 Wp	17	48V 100Ah	7
System variant 2	415 Wp	17	48V 150Ah	5
System variant 3	415 Wp	17	48V 200Ah	4
System variant 4	490 Wp	16	48V 100Ah	7
System variant 5	490 Wp	16	48V 150Ah	5
System variant 6	490 Wp	16	48V 200Ah	4
System variant 7	550 Wp	13	48V 100Ah	7
System variant 8	550 Wp	13	48V 150Ah	5
System variant 9	550 Wp	13	48V 200Ah	4

5. Geographical Location and Solar Path

This research was conducted in the city of Surakarta with coordinates of latitude -7.55^{0}S and longitude 110^{0}E. Surakarta city is located at an altitude of 94 m. Monthly data related to irradiation, temperature, and wind velocity is explained in Table 9. The solar path is shown in Figure 4 which shows the amount of solar accessibility[12].

Table 9 Monthly irradiation data

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Global horizontal (kWh/m^2)	128.2	139.4	132.2	145.8	149.6	151	167.2	180.7	180	191	160.4	155.9	1881.4
Horizontal diffuse (kWh/m^2)	75	81.3	80.3	75.2	67.6	63.7	58.6	66.3	74.0	84.6	89.2	80.7	896.5
Ambient Temperature (^{0}C)	27.3	27.2	27.7	27.8	28.5	27.7	27.6	27.8	28.1	28.8	28	27.6	27.8
Wind velocity (m/s)	1.70	1.70	1.30	1.28	1.61	1.60	1.79	2.00	1.89	1.69	1.20	1.30	1.60

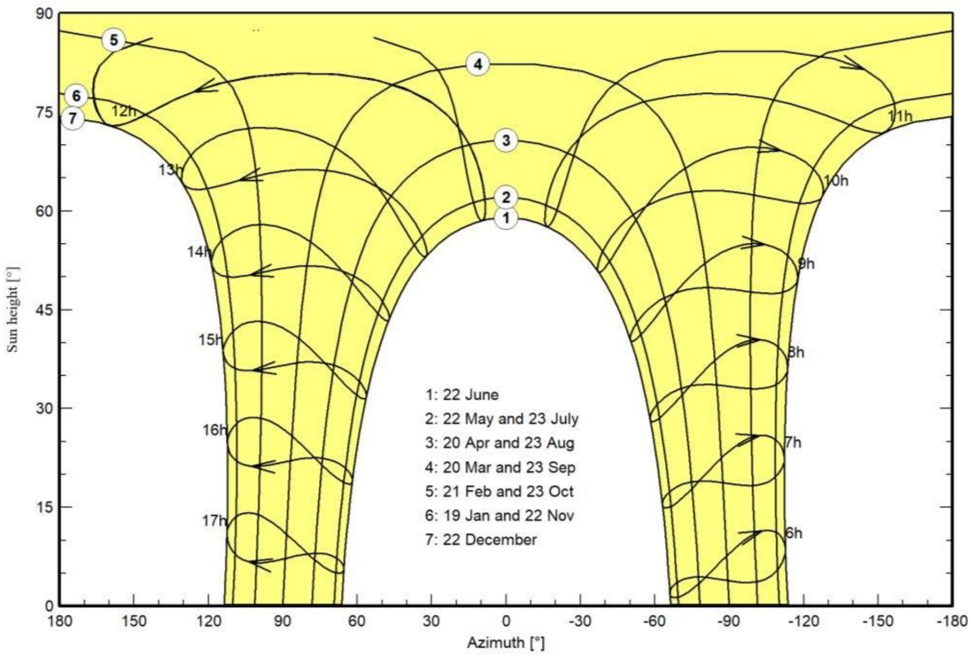

Figure 4 Solar path

6. Simulation

The simulation was carried out using the PVSyst software. All simulation results are according to the proposed site as mentioned in point 4. There are three main parameters as the main input to the defined system variant, namely orientation, user's needs, and system. Main parameter for orientation shown in Figure 3, user's need shown in Table 5, and system variant shown in Table 8. Part specification for system parameter shown in point 3.2, 3.3, and 3.4. The computational modelling has been done within PVSyst software, so only simulation results discussed in this paper.

PVSyst simulation results for all system variant is summarized in Table 10. It can be seen that system variant 6 have the best result over other system variant tested based on the technical indicator assessment shown in Table 1. Based on that result, we follow up on system variant 6 by looking at the PVSyst simulation results in more detail manner.

Table 10

System Variant	**E_Avail (kWh/yr)**	**E_User (kWh/yr)**	**E_Miss (kWh/yr)**	**EUnused (kWh/yr)**	**SolFrac**	**PR**
System variant 1	10.277	10.038.50	2.313,10	46	81,27%	80.41%
System variant 2	10.277	10.054	2.303,10	31,56	81,40%	80.48%
System variant 3	10.277	10.054	2.297,20	24,82	81,40%	80.53%
System variant 4	12.112	11.082	1.269,60	793,40	89,72%	75.18%
System variant 5	12.111	11.113	1.238,40	760	89,97%	75.39%
System variant 6	12.110	11.129	1.222,50	738	90,10%	75.50%
System variant 7	10.209	9.984,60	2.367	32,32	80,83%	80.46%
System variant 8	10.209	9.985,90	2.365,70	27,70	80,84%	80.47%
System variant 9	10.208	9.993,40	2.358,20	18,12	80,91%	80.53%

Shown in Table 11, there are yearly equalizations and fundamental outcomes of PV off-grid system from system variant 6. It can be seen that system variant 6 can deliver electrical energy for the user's need as much as 11129 kWh per year from 12352 kWh needed. We can conclude that there are 1222.5 kWh electrical energy deficit based from user's need. Besides that, there are 738 kWh per year of electrical energy that treated as excessenergy because of full battery capacity.

Table 11

	GlobHor (kWh/m^2)	GlobEff (kWh/m^2)	E_Avail (kWh)	E_Unused (kWh)	E_Miss (kWh)	E_User (kWh)	E_Load (kWh)	SolFrac (ratio)
January	128.8	123.6	820	41.1	268.1	781	1049	0.744
February	139.4	135.1	900	42.2	130.0	818	948	0.863
March	132.2	127.8	848	34.2	235.6	813	1049	0.775
April	145.8	140.9	939	36.3	133.2	882	1015	0.869
May	149.6	144.3	961	10.3	120.1	929	1049	0.885
June	151.0	145.5	976	0.0	69.9	945	1015	0.931
July	167.2	161.4	1079	19.6	0.0	1049	1049	1.000
August	180.7	175.4	1166	76.9	0.0	1049	1049	1.000
September	180.0	174.9	1159	126.2	10.7	1004	1015	0.989
October	191.0	186.0	1227	186.4	33.2	1016	1049	0.968
November	160.4	155.4	1034	90.0	71.0	944	1015	0.930
December	155.9	150.8	1002	74.9	150.6	898	1049	0.856
Yearly	1881.5	1821.1	12110	738.0	1222.5	11129	12352	0.901

The performance ratio (PR) and solar fraction (SF) of simulation results is shown in Figure 5. The PR is the ratio of the final PV system yield (Y_f) and the reference yield (Y_r) with the formula shown in Equation 3. The SF is the ratio of the energy supplied to user (E_User) and the user energy need (E_Load) with the formula shownin Equation 4.

$$PR = \frac{Y_f}{Y_r} \dots\dots\dots\dots\dots\dots (3)$$

$$SF = \frac{E\_User}{E\_Load} \dots\dots\dots. (4)$$

It can be seen that system variant 6 has annual average PR 75.5% with the highest PR 80.1% recorded in July and the lowest PR 67.9% recorded in October. Also, the annual average SF 90.1% with the highest SF 100% recorded in July—August, and lowest recorded SF 74.4% recorded in January.

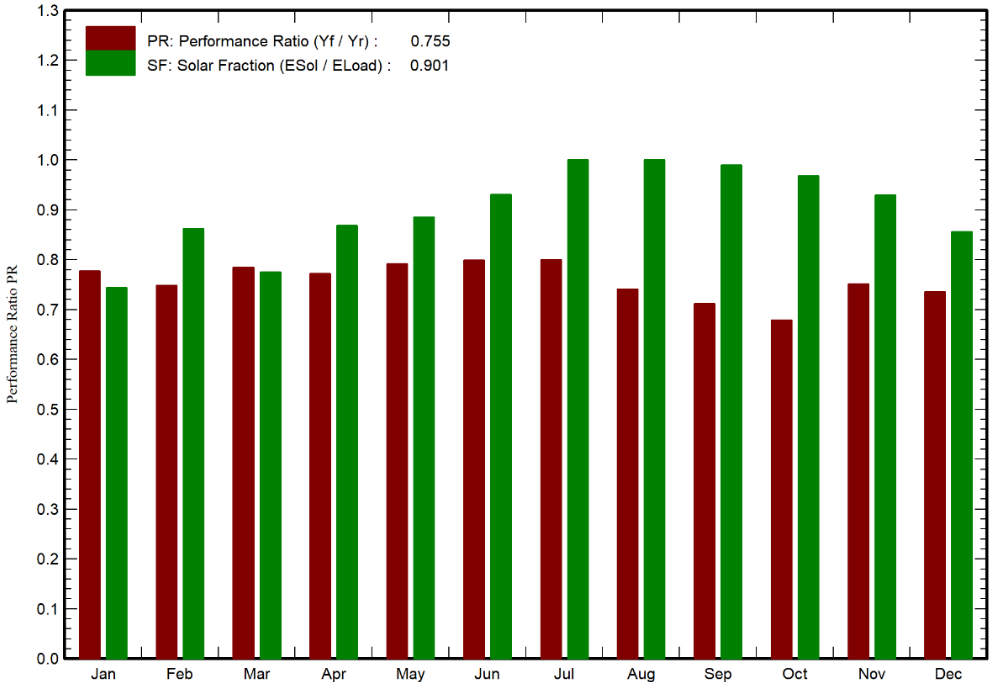

Figure 5

The monthly normalized production and loss factors of simulation results is shown in Figure 6. It can be seen that system variant 6 can deliver 75.5% produced energy to users with total loss of 25.5% energy. Detailed losses of the system are 5.1% from system and battery charging, 14.4% from PV array collection, and 5% from excess energy which the battery cannot accommodate to store.

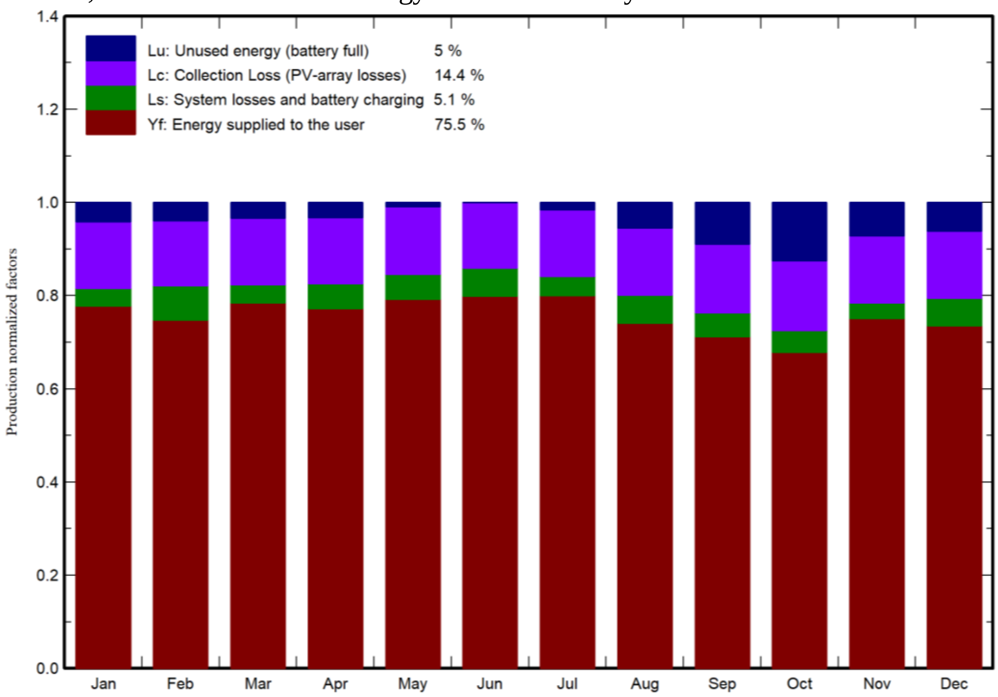

Figure 6

7. Conclusion

This paper presents the results of operational simulation for nine system variant of solar powered mobile battery swap charging station (MBSCS) as shown in Table 10 using PVSyst software. System variant 6 is considered as the best variant among other system variant. Simulation results of system variant 6 is studied further for its performance ratio, solar fraction, monthly normalized production and loss factor.

- From Table 10, it can be concluded that the system variant which used 490 Wp PV module, a universal controller MPPT Converter of 1000 W and 48 V, and battery set of 48 V 200 Ah is the best variant in this study. This refers to the results of the technical assessment.
- From Table 11, it can be seen that solar-powered MBSCS can produce electrical energy up to 12110kWh per year and can supply energy to users of 11129 kWh per year. It also can be known that there are 1222.5 kWh per year of electrical energy deficit because the energy supplied to user are less than the required energy. This is happened because of energy loss to the system and the limitation of the system installed.
- The performance ratio shown that annual average PR 75.5% with the highest PR 80.1% was recorded in July and the lowest PR 67.1% was recorded in October. The diferrence of each month can be affected by temperature, weather, and humidity of the study site.
- The chart results of monthly normalized production and loss factor shows that there are only 75.5%of total energy produced can be supplied to user. There are shown that 5% of total energy producedis not used because the battery set is fully charged. This chart also shows there are 19.5% of total energy produced is loss to the system including PV collection, battery set, and wiring.

Author Contribution: Conceptualization, R.R. and W.S.; methodology, S.F.C.; validation, R.R. and W.S.; data collection,S.F.C.; prototype design, S.F.C.; analysis, S.F.C.; resources, R.R. and W.S.; draft writing, S.F.C; draft review and editing,
R.R. and W.S.; visualization, S.F.C.; supervision, R.R. and W.S. All authors have read and agree to the published version ofthe manuscript

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