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IJIE

Journal homepage: http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

Distribution Voltage in DC Micro-grid System based Solar PV Topologies Configuration in Sarawak, Malaysia

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DOI: https://doi.org/10.30880/ijie.2020.12.06.010
Received 8April 2020; Accepted 4 June 2020; Available online 2 July 2020

Abstract: In the past few decade, longhouse communities in the rural area of Sarawak has been experienced the limitation of electricity supplies. Due to geographic of Sarawak, supply electricity to these rural areas from utility grid through transmission lines also will only results in many losses, the initiation of utilize solar as prime sources is favourable solution. The implementation of DC microgrid system for this area will achieved, as the solar PV system is a DC source to generate electrical supply for appliances in longhouse communities. However, the tropical climate and geographical in Sarawak such as the inconsistent solar radiation, changing temperatures, high humidity and heavy rainfall will be the main restrain to implement solar DC microgrid system. Thus, this paper proposes a comprehensive study about the voltage distribution of DC microgrid configuration in order to investigate system the reliability and efficiency. The configuration of DC micro-grid model has been designed using MATLAB Simulink and an experimental presenting the Simulink also has been developed for validation purposes. The obtained simulation and experimental results confirm that the proposed configuration of the ring system with multiple-sources is more reliable and efficient than radial system with multiple-source configuration in terms of DC voltage distribution at different buses. Thus, the proposed configuration is more reliable according to voltage distribution at each buses.

Keywords: DC microgrid, experiment, modelling, renewable energy, solar photovoltaic

1. Introduction

In Sarawak, the coverage of electricity is the lowest compared to other state in Malaysia. Due to the location that are remote from the electrical grid as well as the variable tropical climate in Sarawak, the community living in these rural places experienced limitation of accessibility to modern world due to the limited accessed to electricity. Therefore, diesel generator powers used for their daily electricity, however the usage of diesel generator cause a high electricity production cost and diesel transportation issues [1]. Other than that, different

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types of renewable energy resources (RES) for example micro-hydro turbine system also being used as electricity sources in the rural area with large number of users [1, 2].

According to Datuk Seri Dr Stephen Rundi Utom, the State Utilities Minister, Sarawak state government target to achieve full electrification by 2025. However currently up to 30,400 households in rural areas had yet to enjoy 24-hour electricity supply [1]. Due to the geographical constraints in installing transmission and distribution to transmit electricity to rural areas, the implementation of renewable energy sources (RES) is the best option since these areas have low demand of load usage [3].

The idea of using renewable energy is a prime priority for developing countries because of the increasing global awareness regarding global climate change and insufficiency of fossil fuels starting 1992 onward [4]. This initiative on renewable energy getting to be more acceptable around the world including Malaysia [1, 2, 5].

Solar photovoltaic (PV) is the conversion of sunlight into electricity directly and heat engine are not required in the process converting the energy compare to other renewable technologies [5, 6]. As reported in [5], solar energy is preferred as main source of electricity and most suitable as renewable energy sources in Malaysia due to pollution-free during electricity generation. Other than that, when comparing the solar power with the other renewable technologies that are existing, the cost of operation is extremely low to build any solar power plant as low maintenance and long term operation. Thus, there is a dire need to come with technological innovation to fully utilize these energy to an efficient models of power generation and technologies to cope with the electricity demand in rural area.

There has been a lot of effort in recent researches to improve on the distribution generations such as grid connected with renewable energy sources [2, 6-12]. To solve the problem of local energy demand, the idea of microgrid came out by connecting distribution networks to distributed power sources such as the local substations with no further expansion of the expensive centralized utility grids [13].

Electric power that flows within a small system with consist of distributed energy as example produced by renewable energy sources (RES) is known as DC microgrid [13]. DC microgrid can be more cost-effective and green environment system when connected with RES as it does not involve in power inverter that consist of extensive use of microelectronic devices which leads to power quality issues [2, 7]. Thus, the technologies of DC microgrid connected to RES currently expanded as more research works being explored to identify new and more efficient models.

Generally for DC microgrid system in rural area consist of maximum total load power roughly about 100 W to 150 W for appliances work on DC. In order to cope with the demand in rural area, investigation on strategy and system configuration that incorporate with renewables energy such as solar need to be done.

Therefore, this paper continue to previous work [14] in order to investigate the reliability of the ring DC microgrid system with renewable energy sources at different bus. Previous focusing on the study two configurations of DC microgrid based on solar PV systems namely, single sources and multiple sources. Both are connected in ring system but solar PV systems connected different buses. The performances of the multiple sources configuration have indicated more efficiency in terms of system reliability and power flow. In order to verify the configuration, this works focusing on the effect of the transmission breakdown between two buses of the multiple sources of ring DC microgrid system. Two DC microgrid system with the multiple solar PV systems will be considered; ring and radial system. The analysis of the system reliability of both DC microgrid system will be analyzed by modelling the system through Matlab Simulink and validate by experimental analysis based on the variations in temperature and irradiance in Sarawak.

2. Modeling

2.1 Model and Data Description

The modelling of the multiple-sources ring DC microgrid system in the Matlab Simulink were initialized from design as shown in Fig. 1. The design ring DC microgrid system based on 3 buses that connected to each other. This system based on multiple renewable energy sources (RESs) that connected to two solar panel but at different bus as supply the electric to the DC load. Each source consist of solar charger controller and battery as energy storage. Generally, each system consists of solar PV panel, solar charger controller, battery and load but different connection between 3 busses. Three LED light bulb and rheostat were connected at each bus for each system act as DC load.

As a starting point, the modeling of the solar PV as source for DC microgrid system were accomplished by using specific input variables based on real data of solar irradiation and temperature [15-17][18]. These input variables have been measured using Tenmars Electronics CO TM-206 and the Non-Contact IR (Infrared) Thermometer which is Extech Instruments 42509 and recorded hourly from 9.00 am to 4.00 pm. Note that the collected data during day-light was utilized as an input into the MATLAB Simulink models of the ring and radial DC microgrid system. The plot pattern data collection of temperature and irradiance as observed in Fig. 2.

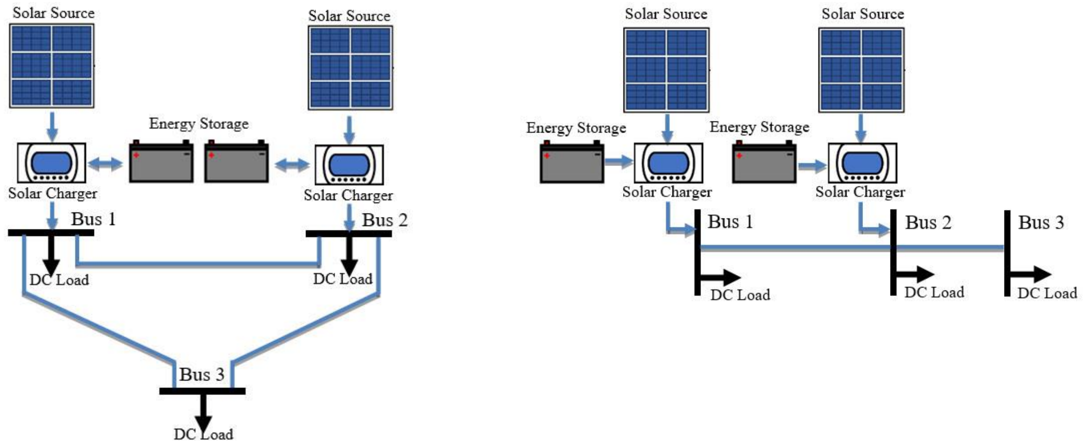

Fig. 1 - Model representation of (a) ring (b) radial DC micro-grid system

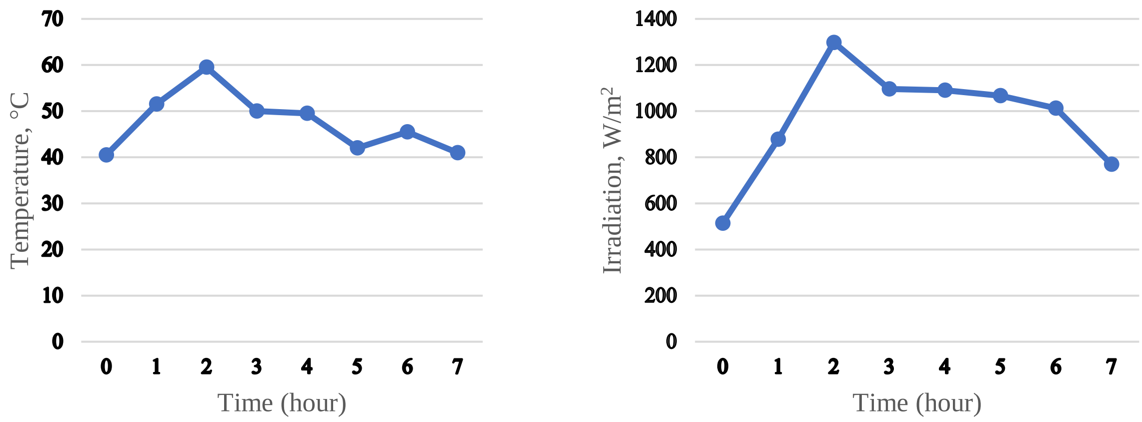

Fig. 2 - Data collection for (a) temperature and (b) solar irradiance on the solar PV

Hardware for both system is constructed to represent the MATLAB Simulink model in order to verify and study the reliability of the system. For this purpose, the transmission line between Bus 1 and Bus 3 is disconnected as shown in Fig. 1. After disconnection line between Bus 1 and Bus 3, the system transforms into new configuration known as radial DC microgrid system. Both models are developed using MATLAB Simulink by considering the changes in the solar irradiance as well as temperature for comparison between simulation and experimental purposes.

2.1 DC Micro-grid Analysis

The AC system in electrical system is commonly simulated using the Newton Raphson method and calculated using equation below [18]:

$$P_i = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \cos\left(\theta_{ij} - \delta_{ij} - \delta_{ij}\right) \tag{1}$$

$$Q_i = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \sin\left(\theta_{ij} - \delta_{ij} - \delta_{ij}\right) \tag{2}$$

But, the admittances matrix reduces and only involve resistive impedance transmission line in DC electrical system, as the transmission not involve the shunt capacitance or series inductive reactance. Besides that no phase or power angle between the voltages buses as reactive power supplied by load connected in the DC microgrid system is assumed zero. Thus, Newton Raphson formulation for DC system is such an equation below [18]:

$$P_i = \sum_{j=1}^{n} |V_i| |V_j| |Y_{ij}| \quad (3)$$

Hence, due to its simplicity and robustness, it help engineers and contractors to save time for power flow analysis while having almost reliable approach during planning stage and before proceed to the installation of the DC microgrid system [19].

3. Distribution DC Voltage Results and Discussion

This section evaluate the results generated from the simulation and hardware experiment that aim to analyze the ideal system for DC microgrid. The analysis was carried out for two voltage levels;12V_{DC} and 24 V_{DC}.

3.1 Distribution voltage at 12V_{DC}

Fig. 3 show the DC distribution voltage for each bus in each system based on the hardware experiments. There is difference in the values of the distribution voltage for various buses in each system even I t operates at same DC level. The pattern of distribution voltage obtained was different between this two system by comparing simulation and hardware experimental results. The distribution voltage for ring system was found with the range between 12.8 V_{DC} to 13.4 V_{DC} based on the simulation and hardware experimental results. Based on the hardware experimental input voltage measured form PV controller, the input voltage obtained with the average 13.4V, hence having to say that the voltage at each bus for this configuration is ±0.6 V_{DC} of its input voltage.

Besides, constant patterns the value of the distribution voltage lie on same point for each bus was observed according to simulation analysis for the radial system, ranging from 4.0 V_{DC} to 4.2 V_{DC} with the input voltage at average of 12.5V. Meanwhile, the hardware experimental analysis of distribution voltage for each bus in the radial system is from 4.4 V_{DC} to 5.0 V_{DC} which is much lower than distribution for the ring system even though the average source voltage obtained from the experiment is 14.2 V_{DC}.

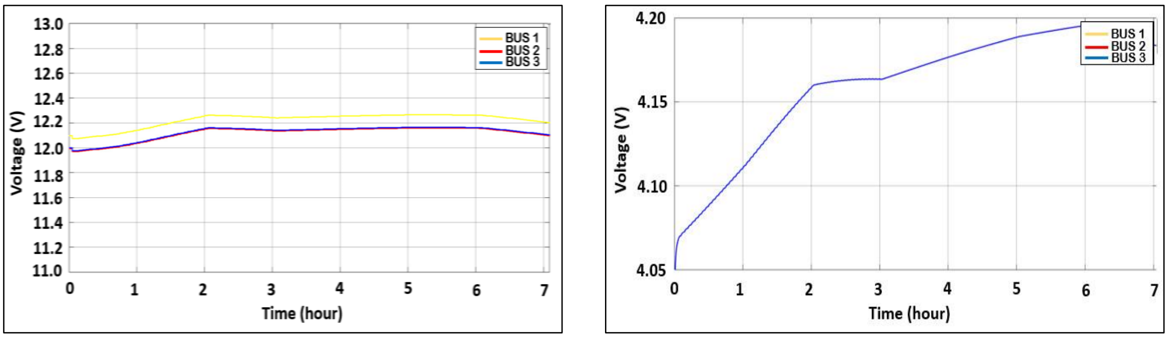

Fig. 3 - Distributed voltage each bus in the simulation of (a) ring and (b) radial DC micro-grid system at 12 V_{DC} level

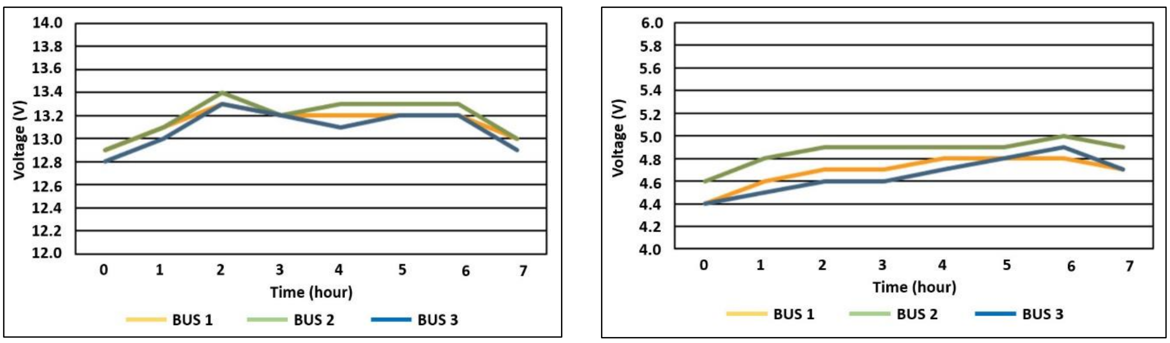

Fig. 4 - Distributed voltage each bus in the experimental of (a) ring and (b) radial DC microgrid system at 12 V_{DC} level

Despite that the distribution voltage at each bus are smaller in the radial system compare to the one in ring connection, the buses are sharing the equal amount of voltage as need to divide the source voltage among all the buses according to [20, 21]. Thus, the higher the number of loads, the smaller the voltage obtained by each load. This is a significant point for ring system because all the loads receive equally values or reliable of distribution voltage from the source as claimed in [20].

3.2 Distribution voltage at 24V$_{DC}$

DC microgrid system at 24 V$_{DC}$ were carried out using the same method as before but different voltage level. The reconnection of two 12 V$_{DC}$ battery in series for both systems to obtain at desired level. The DC distribution voltage are analyzed based on this scenario according to Simulink models simulation and hardware experimental. The results for both systems are depicted in Fig. 5 (simulation) and Fig. 6 (hardware experimental).

As depicted in the Fig. 5 and Fig. 6, same pattern of the distribution voltage can be observed based on simulation and hardware experiments. Note that the voltage distribution in Fig. 5(b) also was observed lie on the same point and the graph each bus was overlapping produce a single line based on the simulation result which ranging between 8.17 V$_{DC}$ to 8.38 V$_{DC}$. From the analysis on simulation data for the ring system that was shown in Fig. 5, the voltage for each bus is ranging between 24.1 V$_{DC}$ to 23.6 V$_{DC.}$ The simulation also reinforced by the hardware experiment where the results show the similar pattern with slight increment of value up to 29 V$_{DC}$ with the input voltage obtained at 28.8 V$_{DC}$. Nevertheless, that point where at the time when solar radiation is higher as well as the operating temperature also at the higher region (Fig. 2). Thus, it is noteworthy that ring connection with the buses do not have to divide the source voltage among themselves and receive close to equal value of source voltage similar to that mentioned in [22]. For the radial system, the input voltage obtained is at the average of 25 V$_{DC}$ while the voltage at all the three buses are ranging from 8.19 V$_{DC}$ to 8.38 V$_{DC}$ based on the hardware experimental analysis.

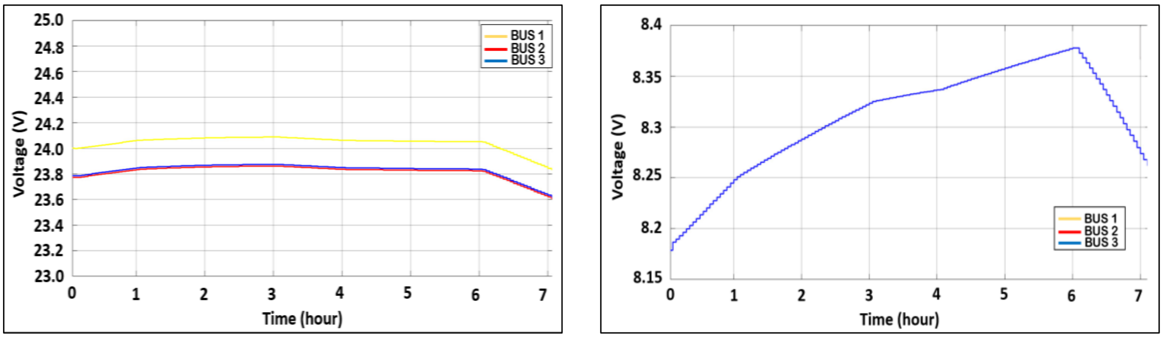

Fig. 5 - Distributed voltage each bus in the simulation of (a) ring and (b) radial DC microgrid system at 24 V$_{DC}$ level

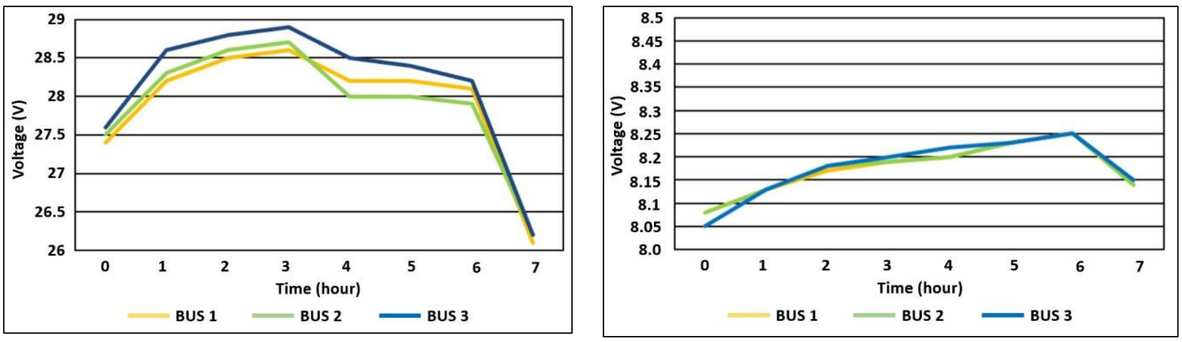

Fig. 6 - Distributed voltage each bus in the experimental of (a) ring and (b) radial DC microgrid system at 24 V$_{DC}$ level

The simulation also shows the similar patterns of resulting voltage at each bus as in the experimental results. The results showed that the voltage distribution in the radial system lower than the ring system as analyse between simulation and hardware experimental results. According to [20-21], the buses are sharing the equal amount of voltage but need to divide the source voltage among all the buses and therefore, the higher the number of loads, the smaller the voltage obtained by each load. The different behaviour of different voltage distribution level between ring and radial system is observed where the ring system are experienced higher distribution DC distribution voltage for various buses than radial system, same as mentioned in [23-25].

As the voltage level increasing from 12 VDC to 24 VDC, the DC distribution voltage for various buses in the ring system experienced same level as input voltage. It is summarized that the level DC distribution voltage for various buses become greatly reduced to certain level. It is observed that a major amount of power losses occured when using a heavy load with low voltage levels as investigated in [26, 27]. Thus, ring system produce more reliability and flexibility in terms of DC voltage distribution, hence making the ring system is optimal configuration in DC microgrid system [21, 23, 25].

4. Conclusion

DC microgrids generally an alternative approach to traditional AC grids for rural area application. In this paper, an effort has been made to analyze the ring and radial DC microgrid system integrated with renewable energy sources (RES) that connected at different buses. The approach and analysis through the verification of the simulation and experimental results for radial and ring system was carried out to identify the optimal configuration. Simulation and hardware experimental results established that reliable of using the ring system for DC microgrid at Sarawak in term of distribution voltage level at each buses. The ring DC microgrid system revealed that this configuration is not only reliable at lower voltage level (12 V_{DC}) but also proven to be flexible and efficient when tested at different voltage level which is at 24V. This configuration can be applied at villages in rural area with constant DC power loads.

Acknowledgement

This work is carried out with financial support under F02/SpSTG/1568/2017 grant and the authors are grateful to the Universiti Malaysia Sarawak for the support.

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