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Design and Implementation of 5 kW Smart DC Microgrid

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Abstract - **This paper presents a design for electrification of a remote village with the help of locally generated renewable electricity from solar PV modules. The whole system setup works on DC. Regulated DC bus is efficiently used to power up DC fans, DC lights in the houses of the selected village. Remote Monitoring System is used in order to continuously monitor the power plant and control the power plant. The main reason to go for DC microgrid rather than AC grid is to avoid the problem of losses and power factor. A 5 kW DC microgrid consisting of a 5-kW solar PV array and a 96V, 200Ah battery bank is developed. The system is simulated in MATLAB for a variety of operating conditions and results are presented.**
Keywords: **DCMicrogrid, Smart Grid, Village Electrification, Rural Electrification, Remote Monitoring System**

I. INTRODUCTION

The world today is seeing a rapid change in the way we use energy. The energy industry is slowly transitioning from a centralized form of generation to a distributed one, in the form of microgrids. The rapid fall in the price of solar panels, wind turbines, and batteries are accelerating this transition and the proliferation of consumer appliances such as cell phones, laptops, etc. which inherently use DC has encouraged the development of a DC distribution network. Major energy savings and exciting improvements in quality of life can be realized simultaneously by new electronic energy conversion systems in all energy consuming devices, from pacemakers to home appliances to electric vehicles.

As of 2012, 304 million Indians (24 percent of the population) were un-electrified. India has 18% of the world's population but 30% of the world's population is without electricity [1]. According to the International Energy Agency (IEA), more than 300 million Indians lacked lack access to electricity in 2017. One out of each 5 individuals around the world while not access to power lives in the Republic of India. Rural households in 9 out of the 28 states - Arunachal Pradesh, Bihar, Haryana, Jammu & Kashmir, Jharkhand, Karnataka, Mizoram, Sikkim, and Uttar Pradesh receive less than 18 hours of power supply in a day. Still, 580,376 households lack access to electricity. In view of providing reliable electricity to these people, renewable energy solutions with storage are becoming popular. In areas where the cost of bringing the conventional grid is high, off-grid solutions are being implemented [3].

Nowadays the demand of the DC grid compared to the AC grid is increasing. To meet the demands and for the betterment of our future, the research on DC grid to electrify the rural areas is also increasing in numbers [4]. DC microgrid maximizes the use of renewable energy. The main reason to use DC microgrid rather than AC grid to avoid the problem of losses and power factor. Present utility system provides AC which means the AC quantity is converted into DC before it is utilized. So, in DC microgrid the numbers of power converters are also less than the AC grid as it does not need the intermediate power conversion (AC to DC). Using a DC microgrid system reduces the overall losses and energy consumption to meet the same needs.

Over 50% of the electrical appliances in a typical household such as LED lights, laptops, LED TVs, cell phones, computers, washing machines (if variable speed drives are used) use a final dc input whereas our supply today is AC. This offers an opportunity to use DC from renewable energy systems directly and avoiding the losses inherent in converting power to alternating current (AC) and back. A DC Microgrid eliminates or minimizes the AC-DC or (DC-AC-DC) conversion losses to 10%-15% from the existing 20%-40% by using a single high-efficiency rectifier instead of using multiple rectifiers of low efficiency. The AC supply from the utility is rectified at the high device level usually by an inefficient rectifier.

A residential DC distribution architecture can save about 7% of total house electricity consumption for the non-storage case and about 13% for the storage case [2]. This is in addition to the substantial (about 33%) energy savings that are obtained by switching the entire load to efficient DC-internal appliances. The DC approach will eliminate many AC-DC converters embedded in appliances and replace them with a centralized high-efficiency rectifier and a couple of DC-DC converters.

A salient property of the DC microgrid design is that the distributed management of the grid voltage, that allows each fast power-sharing, and a metric for decisive the accessible grid power [5]. The most necessary advantage embodies higher dependableness and potency, less complicated management and natural interface with renewable energy sources, and electronic masses and energy storage systems [6]. Another compelling reason to go ahead with DC Microgrid is the superior compatibility of DC power with storage. A key feature of a Microgrid lies in their ability to be connected with each other and also the macro grid. They benefit not only utilities but also the consumers to a large extent.

II. OVERVIEW OF THE VILLAGE

A. Village Layout: Thevillagewhere the project is implemented is a remote village, which is situated far from the city place. An institution in Bangalore has selected this village for smart village scheme and funding the project. People in this village needs to travel around 3 Km to catch a bus or shop anything. The village has 20 houses and people's occupation here is farming. The village has two pumps, one used for the farming purpose and another for household purpose. Hence, we propose to give each home with one overhead tank and supply water through the solar connected pump to houses. They get only around 4 hours of electricity from grid supply in the early morning time to pump their motors. Hence, we propose to put up a 5-kW solar system for Solar Pump and electrical loads for 20 houses. A survey was carried out and the layout of the village is as shown in Fig. 1.

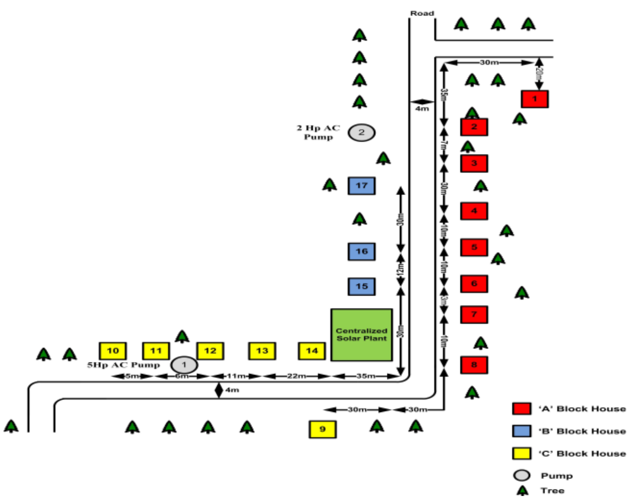

Fig. 1 The layout of the Village

III. DESIGN AND SPECIFICATIONS OF THE PROPOSED SYSTEM

B. Design of Proposed System: The proposedDCMicrogrid architecture is as shown in Fig. 2.

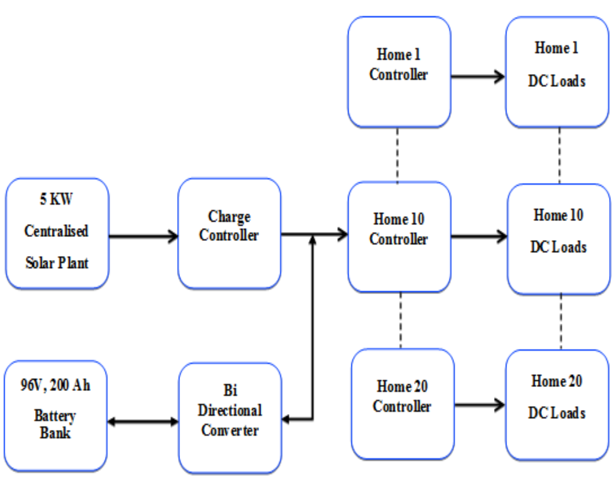

Fig. 2 Block Diagram of Proposed System

The village consists of 20 houses, and as the system is designed for DC Microgrid, the villagers are provided with DC loads. The system consists of 5 KW centralized solar power plant, containing 16 panels of 320Wp each connected as four parallel strings. Each string consists of four panels connected in series. The system is standardized for 12V since the loads supplied are of 12V. The battery bank is developed to supply the loads in the night time. The battery is charged and discharged with the help of the charge controller and Bi-Directional Converter.

The charge controller is mainly used to buck the output from the solar plant as the output is higher than the battery's voltage. And Bi-Directional converter maintains the DC bus voltage of the system. The system is said to be "Smart DC Microgrid" since the system consists of Remote Monitoring System, from which the system is monitored and controlled from a remote device like PC or Mobile. Each house is supplied with three DC LED Lights, one DC Fan and one home controller. The home controller is a buck converter and remote monitoring unit to control the load cut off. Proper protections like earthing, MCB, SPD, AJB, blocking and bypass diodes have been included in the design.

C. Technical Specifications of Proposed System

1. Solar Panel Specification: For Household loads, 4 panels are connected in seriesand 4 such strings inparallel. And for pump usage, all panels are connected in series.

TABLE I SOLAR PANEL SPECIFICATION

No. of Panels	16
Single Solar Panel Capacity	320 Wp
V_{OC}	45.7 V
I_{SC}	9.06 A
V_{MP}	37.1 V
I_{MP}	8.68 A
η	16.41 %

2. Charge Controller Specification: Charge Controller here is the combination of a DC-DC Converter and PID Controller.

TABLE II CHARGE CONTROLLER SPECIFICATION

$V_{in,\ min}$, $V_{in,\ max}$	110 V, 150 V
V_{out}	110V
Inductor(L)	2.89 µH
Capacitor(C)	0.189 mF
Dutymax, Dutymin	1, 0.73
Switching Frequency(f_s)	20 kHz

3. Home Controller Specification: Home Controller is a combination of Buck Converter and RMS unit.

TABLE III BUCK CONVERTER SPECIFICATION

V_{in}	110 V
V_{out}	12 V
Inductor(L)	0.24 mH
Capacitor(C)	86.81 μF
Duty Cycle(D)	0.11
Switching Frequency(f_s)	20 kHz

The values of critical inductance and capacitance for the buck converter are determined by following formulae:

$L=D(1-D)^2R / 2f_s$ (1)

$C=D / R(\Delta V_O/V_O)f_s$ (2)

Where $\Delta V_O/V_O$ is percentage ripple in the output voltage and R is total load resistance.

IV. MATLAB MODELING

The proposed system is simulated using MATLAB/SIMULINK.

A. Solar PV Model

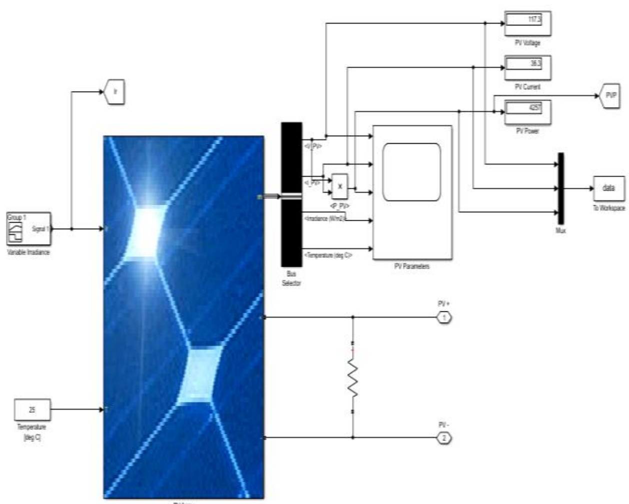

Fig. 3 Solar Model with Variable Irradiation

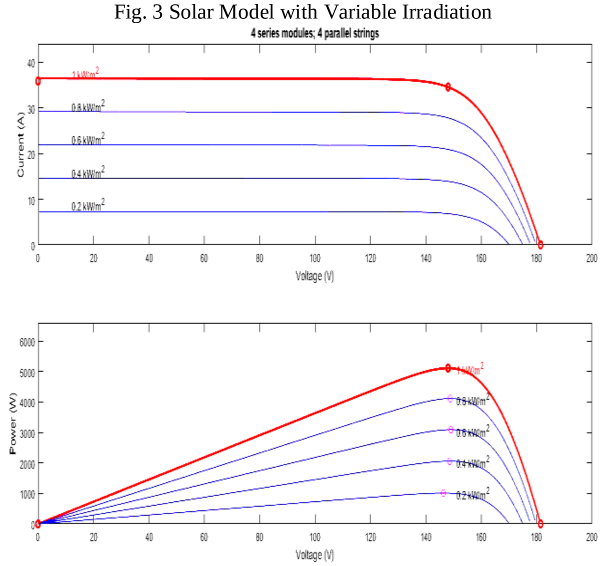

Fig. 4 PV and IV Curves for different Irradiation

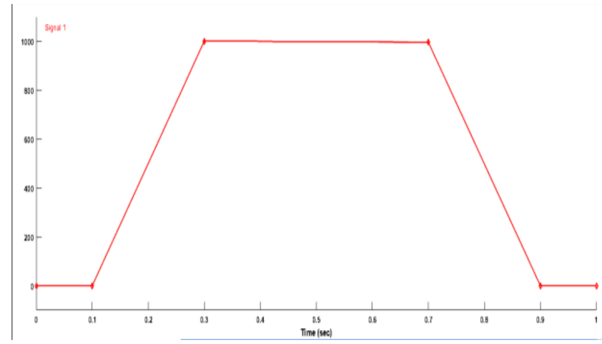

Fig. 5 Variable Irradiation profile

Fig. 3 shows the PV array model with voltage and current measurements [7]. This model is tested for household loads; hence PV array configuration gives a maximum of 150V output. Fig. 4 shows the PV and IV curves for different irradiations. Fig. 5 shows the variable irradiance profile, varying from 0 W/m2 to 1000 W/m2.

B. Charge Controller and Battery Model

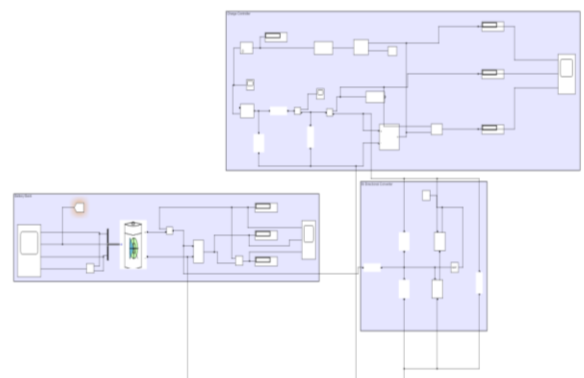

Fig. 6 Charge Controller with Battery Bank

Fig. 6 shows the model of the Charge Controller. The charge controller is a device which helps the battery bank to charge or discharge and maintains the battery's SOC level. Here, the charge controller consists of a loop with a PID controller to maintain the DC bus voltage to 110V. A charge controller is associated with a Bi-Directional controller to provide a circuit for the battery to charge and discharge through [8].

C. Home Loads and Buck Converter Model

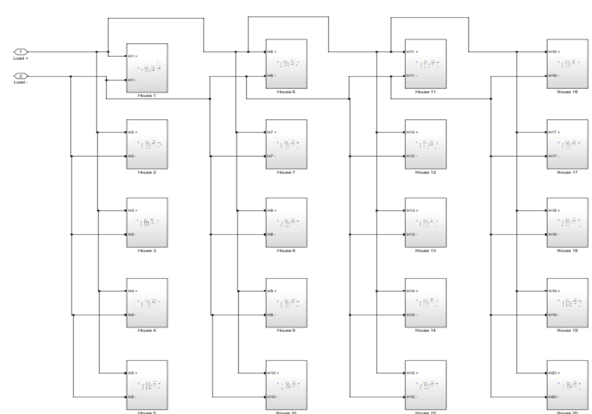

Fig. 7 Home Loads

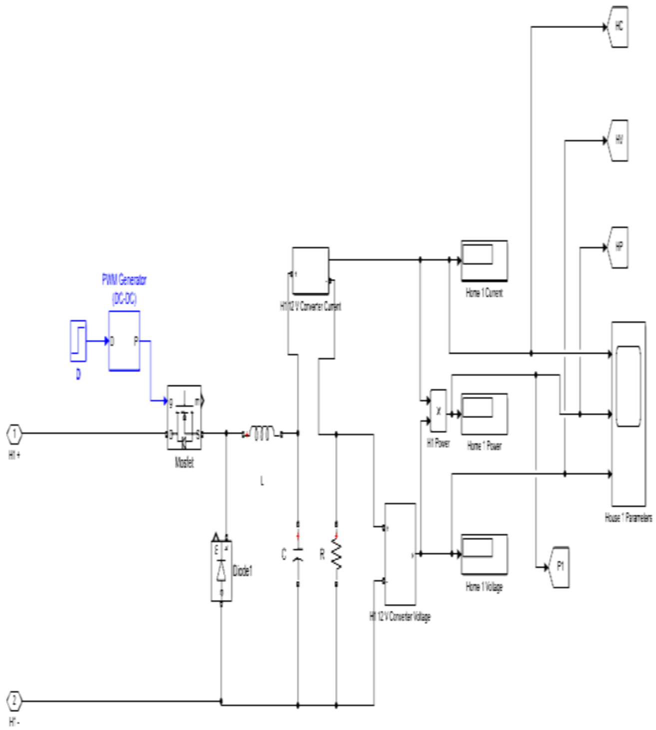

Fig. 8 Buck Converter

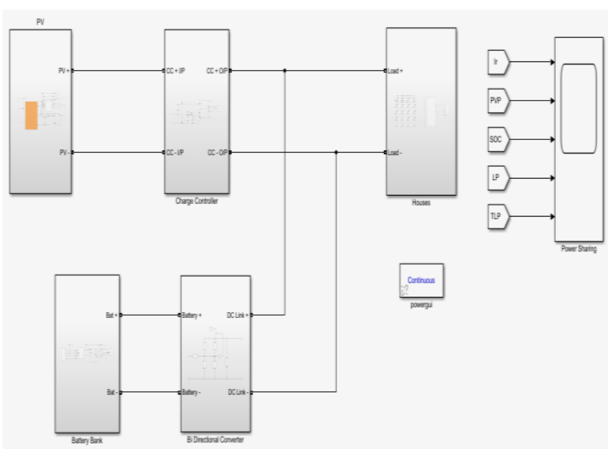

Fig. 9 Overall MATLAB model

V. RESULTS AND DISCUSSION

The main issue in any microgrid is integrating the sources and maintaining the constant power supply to loads. In this DC microgrid system, only Solar Panels and Battery Bank are sources and hence the simulation is done in order to check the power-sharing capability of battery with PV in order to maintain constant power supply for DC loads.

A. System Performance During Peak Irradiation

The system is tested for peak irradiations, i.e. from 800 W/m^2 to 1000 W/m^2. PV array's voltage, current, and power will vary according to the change in irradiation.

<Total Load Power>

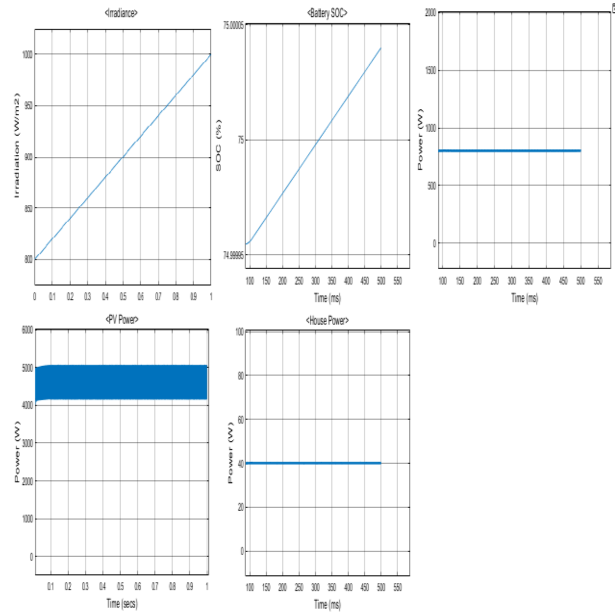

Fig. 10 System Parameters under Peak irradiances

From Fig. 10, it can be observed that, as the irradiation varies from 800 W/m^2 to 1000 W/m^2, PV power also varies between 4 kW to 5 kW. Since the PV power is much greater than total load power, the battery keeps on charging and PV supplies power for both load and battery bank. It's important to observe that, the load is being supplied without any disruption.

B. System Performance During Night Time(PV Shutdown)

The system is tested for night time condition, i.e. no solar irradiation and hence no input from the solar PV array. The only source available in this condition is the battery bank.

<Total Load Power>

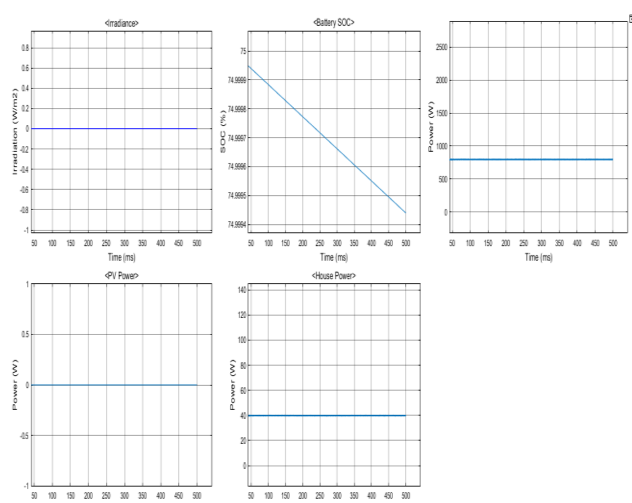

Fig. 11 System Parameters during PV shutdown

Fig. 11 depicts the case of PV shutdown in the night time. Hence, the only power source in the system will be the battery bank. From Fig. 11. It can be observed that PV power is zero as radiation falling on the PV panel is zero. Therefore, battery continuously discharges in order to provide power to the loads. And here also, the load is being supplied without any disrupt in power.

C. System Performance for a Whole Day

This is a real-time scenario, where the irradiation varies from zero to maximum irradiance over a day. In real time, irradiance during the early morning will be very less and keeps on increasing as the day prolongs. Irradiance will be maximum during solar noon and again keeps decreasing as the evening approaches. During night time, irradiance will be zero.

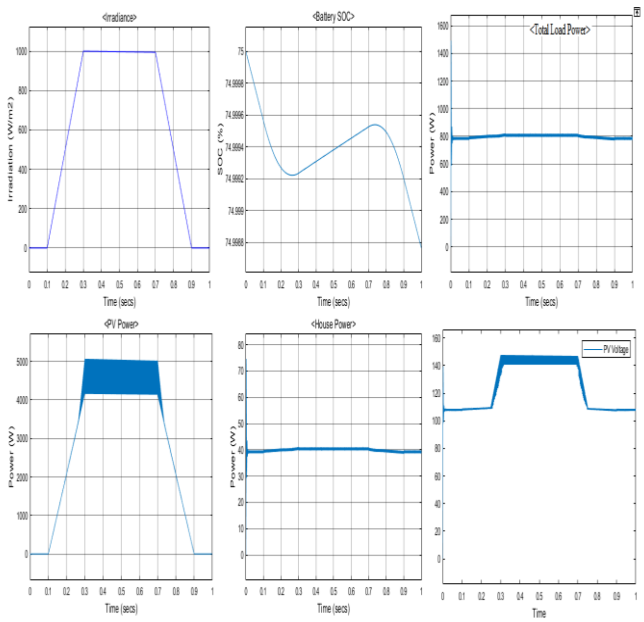

Fig. 12 System Parameters over a day

Fig. 12 is the performance graph of the real-time scenario of the system. It can be observed that irradiation is varied from zero to maximum and then again maximum to zero, as in a real day. According to the variation of irradiation, PV voltage and power are varied. It can also be observed that, when there is less irradiation battery is discharging and when there's high irradiation, the battery is charging. This means battery and PV are sharing power in order to supply constant power to the loads. Fig. 12 also shows that there's no disrupt in load power. This proves that the proposed system is designed for the real-time scenario with the integration of sources and maintaining constant power to load.

VI. CONCLUSION

In this work, a 5 kW DC Microgrid is designed, and simulation was developed. The system was simulated in MATLAB/Simulink for severaltest conditions such as peak irradiance, variable irradiance, shutdown of PV, etc. and results are presented. The paper describes the integration of power electronics converters with renewable energy sources. The results show that the DC system is preferred to conventional AC grid. A hardware implementationhas been carried out for the proposed system. Further work is in progress to collect data from hardware implementation. A provision can be implemented to provide overload protection using a closed loop in MATLAB simulation as the future scope of the project.

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