A Grid-Connected DC Microgrid Application for a Typical School Load Demand

Mohd Alam
Photovoltaic laboratory, Centre for Energy Studies
Indian Institute of Technology Delhi
New Delhi, India
gbpec.mohd.alam@gmail.com

Kuldeep Kumar
Photovoltaic laboratory, Centre for Energy Studies
Indian Institute of Technology Delhi
New Delhi, India
kuldeepnitb@gmail.com

Viresh Dutta
Photovoltaic laboratory, Centre for Energy Studies
Indian Institute of Technology Delhi
New Delhi, India
viresh_dutta@yahoo.com

Abstract— **DC microgrid can work in autonomous or grid-connected modes. In autonomous mode, there is need of energy storage medium such as battery to store the excess electricity along with the load feeding that increases the additional cost. Whereas, in grid-connected mode the excess electricity can be exported to the mains-grid to earn the profit through net-metering. In this study, an application of DC microgrid based on photovoltaic (PV) generator to meet the load demand of a typical school is reported. In schools, the major load demand occurs in the day time during working days while load demand decreases during night time, weekends, summer and winter vacations. The load demand also vary according to the seasons such as summer and winter. Therefore, surplus PV power is available to export to mains-grid and earn profit. In day time, if PV is more than load demand then the excess PV electricity is fed to the mains-grid and if PV is not sufficient to supply load then deficit power is imported from the mains-grid. The performance analysis of DC microgrid is done for various operating load profiles according to different seasons such as summer and winter using the Hybrid Optimization Model for Electric Renewables (HOMER) software. The results shows that the net-metering approach for the school load application provides economically viable approach.**

Keywords— DC microgrid, Grid-Connected, HOMER, Net-Metering, Photovoltaic

I. INTRODUCTION

In India more than 75% population lives in rural areas. More than 43% rural households uses kerosene to light their houses. Approximately 21138 village (4%) are deprived of electricity [1]. More than 85% people in rural areas uses wood, cow dung, crop residue as primary energy sources to meet energy demand. The main reason of this, electricity infrastructure is unavailable or very weak to these remote locations. Deen Dayal Upadhyaya Gram Jyoti Yojana scheme is launched by Government of India to electrify the rural India [2]. Ministry of New and Renewable Energy (MNRE) started the Jawaharlal Nehru National Solar Mission (JNNSM) to supply 100 GW electricity demand by on- grid or off-grid solar photovoltaic (SPV) system by 2020. MNRE has started an initiative program to develop the DC microgrid activities in India [3, 4].

Microgrid is a small scale electric grid than can provide power to the local load in conjunction with the mains grid or autonomously. It consists of renewable power generators such as PV, fuel cell, biomass etc. along with storage medium and the grid connectivity. However, the microgrid can be categorized in two sections: AC microgrid or the DC microgrid [5]. In recent years, DC microgrid is gaining popularity because of the higher system efficiency, less complexity, reduction in the multiple power converter stages compared to that as in the AC microgrid [6, 7]. In application of AC power to meet the household load demand, major loads such as LED light loads and power electronic devices have multiple power conversion stages which reduce the overall system efficiency. This multistage conversion losses can be reduced by using DC power supply [8]. In present scenario, most of the loads i.e. LED lights, computer/mobile charging etc. are inherently DC in nature. Therefore, these loads can be supplied by the use of DC microgrid [9]. The use of microgrid gives the flexibility to meet the load locally in the areas where there is no access of electricity and also where there is access of mains-grid. DC microgrid can operate in different modes such as standalone, grid-connected and hybrid AC-DC modes according to working load requirement [10]. Several studies has been performed for sizing and designing of AC, DC and hybrid AC-DC microgrid in simulation domain [11-14].

In this paper, the study is done on DC microgrid application for a typical school load demand. The DC microgrid is designed with the grid-connectivity using solar PV as power generator. If there is excess PV production then excess electricity is fed to the grid. In case of PV power is not available or insufficient than load is met by the grid. The simulation study of grid-connected DC microgrid is done using Hybrid Optimization Model for Electric Renewables (HOMER) software. HOMER simulation tool is developed by the national renewable energy laboratory (NREL) that is used in designing, sizing, and techno-economic evaluation of renewable power generators based microgrid [15]. Present study shows the techno-economic feasibility of PV based DC microgrid for a typical school for different load profiles according to academic seasons. Profit earn aspects is also captured, using the net metering concept in such type of microgrid for school load demand. The payback period of the system is also evaluated in order to assess the economic effectiveness of the system. The electricity exported to the mains grid after payback period is used to earn the net profit.

The present study is summarized in following manner. Section II and III gives the system description and results and discussion respectively. A comprehensive conclusion of the study is discussed in section IV.

II. DC MICROGRID SYSTEM

The DC microgrid system is designed and studied for a typical school load application for Roorkee (29051.3'N, 77053.3'E), India location. Due to minimal night load requirement in a typical school, the energy storage medium can be eliminated. Thus, surplus PV electricity can be exported to grid to earn profit. Therefore, in present study, grid-connected DC microgrid is designed using PV as primary power source. The load demand in a school is maximum during the summer months (excluding the summer vacations in May-June). While during winter time load demand decreases as compared to summer load demand. The schematic diagram of the grid-connected DC microgrid is shown in Fig.1.

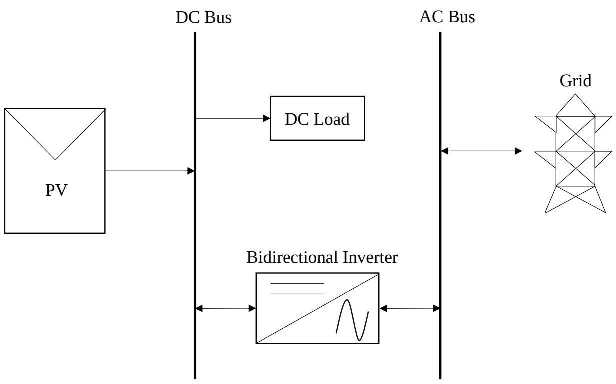

Fig.1 schematic of the grid-connected DC microgrid

PV modules produces the DC electricity during the daytime using the incident solar irradiance. The output of PV system is supplied to the load via. DC bus. Export and import of grid power during the excess and deficit PV power respectively is facilitated by the bi-directional inverter.

A. School load profile

The school taken in this study have one principal and staff room, 14 classrooms, one computer lab, and one office room. There are also other loads such as street, corridor lights and drinking water pump motor. The major loads are used LED lights, fans, air-conditioner for principal room and computer lab and motor for drinking water application. In present study, these load are operated at DC power. The total requirement and rating of DC load is shown in Table I

Table I. SPECIFICATION OF DC LOADS

Load	**Power (W)**	**Quantity**	**Total power (W)**
LED light	16	70	1120
Fan	24	39	936
Air-conditioner	1000	2	2000
Computer	60	10	600
Motor	500	1	500
Total load			**5156**

The load profiles for a typical day in summer, winter and vacation months are shown in Fig.2, Fig.3 and Fig.4 respectively.

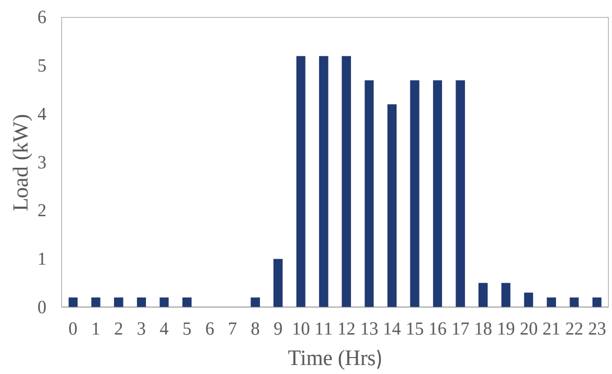

Fig. 2 Load profile for a typical day in summer

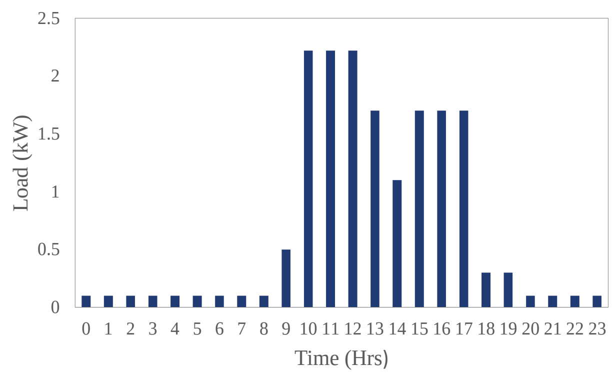

Fig. 3 Load profile for a typical day in winter

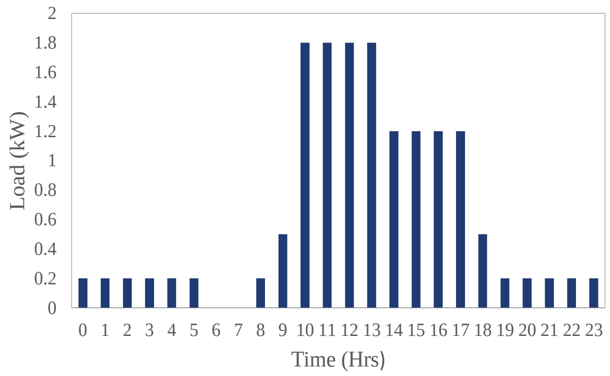

Fig. 4 Load profile for a typical day in vacation

B. Resource data

The solar radiation and temperature are taken from National Renewable Energy Lab Database and NASA Surface meteorology and solar energy database respectively [16], [17]. The resource data contains hourly weather data such as solar radiation and temperature etc. for a given latitude and longitude of a location. The global horizontal irradiance and hourly temperature are obtained for Roorkee, India location as shown in Fig.5 and Fig.6 respectively.

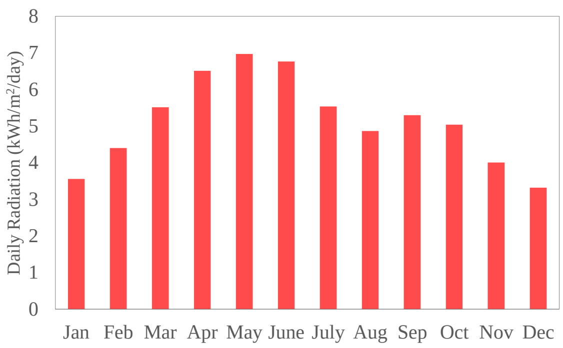

Fig. 5 Monthly average daily radiation profile for a year

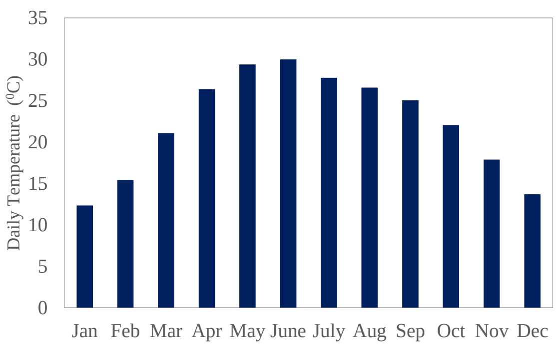

Fig. 6 Monthly average daily temperature profile for a year

III. RESULT AND DISCUSSION

The HOMER simulation results for the present DC microgrid system is explained as:

The variation in the load demand throughout the year is shown in the Fig.7. It can be seen that the maximum load demand occurs during the summer months. However, the load demand is lesser during winter and vacations months as compared to the working summer months. Peak load demand is found to be ≈ 5.2 kW.

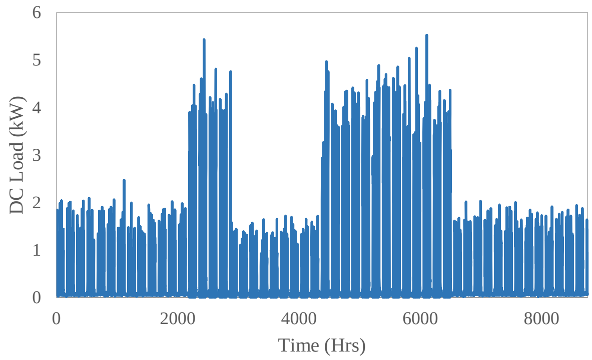

Fig. 7 Yearly load variation

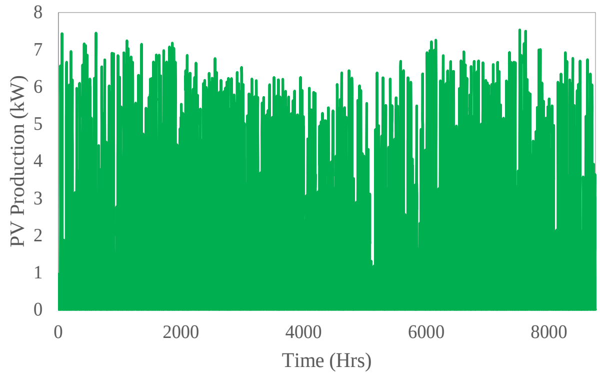

Fig. 8 Yearly PV power production

The yearly power production by the PV system is shown in the Fig. 8. The PV power production from the PV system is obtained at maximum power point (MPP). The electricity unit generated by the PV system is more during months i.e. March, April, May, September and October. It is because, received solar irradiance is more during these months as shown in Fig.5. While PV electricity production is lesser during the months i.e. January, February, November, December as received solar irradiance is lesser. However, PV electricity production is also lesser during months such as July to September. Irradiance is higher during these months but due to rains, average PV electricity production is lesser. Maximum power produced by the PV system is ≈ 7. 2 kW.

The yearly power exported to the grid from the PV system is shown in the Fig.9. As it has been shown the yearly load demand and PV power production therefore, excess PV electricity is exported to the mains grid. As maximum excess PV power occurs during the summer vacation months because PV electricity production is higher and load demand is minimum. Therefore, maximum electricity is exported to the grid to earn the profit. Net metering concept shows the suitable application in such cases to earn the maximum profit with present scenario.

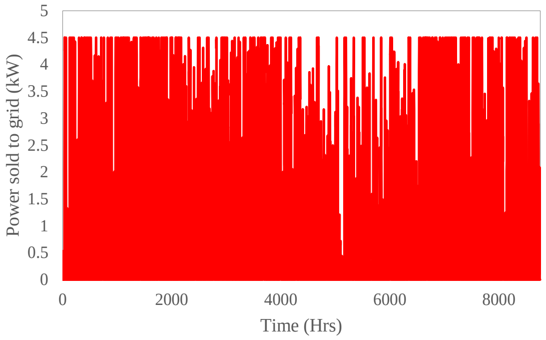

Fig. 9 Yearly power sold to grid

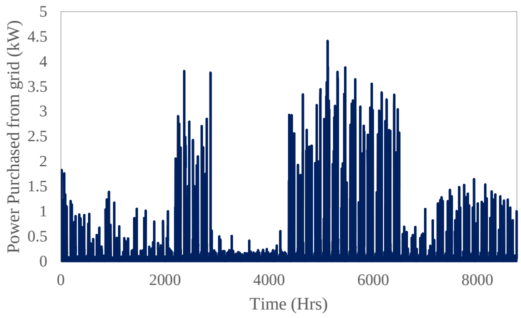

Fig. 10 Yearly power purchased from the grid

The electricity imported from the mains grid throughout the year is shown by Fig. 10. Electricity imported from the mains grid is maximum during the rainy months i.e. July to September as PV electricity production is lesser. Therefore, electricity is imported from the main grid to supply the required load demand in absence of sufficient PV power. However, there is need of electricity import from the mains grid throughout the year as there is requirement of lights load in street and corridor during the night time when PV power is unavailable.

A comprehensive analysis of DC microgrid performance for throughout the year is given in the Table II. The optimized PV capacity for different load profiles is obtained ≈ 7.5 kW from the HOMER simulation results. The average electricity output per diem is ≈34 kWh. As PV electricity production (12574 kWh) is higher than total load demand (5215 kWh) therefore, there is possibility to export the excess electricity to the mains grid. Net yearly electricity export to grid is 7359 kWh. In order to export the power to the grid, the rating of inverter is optimized to 4.5 kW. However, there are the losses associated in the inverter and rectifier which is 5. 2 % of total electricity exported to main grid in year. For a year span these losses have significant amount and for system designer, these losses are very important to be considered. These losses can be reduced by adopting highly efficient inverter-rectifier technology.

Present DC microgrid shows the promising sustainable development by reducing the harmful emission to meet the load demand. If the entire load demand is met by the grid electricity then corresponding CO_2 emission is 3296 kg. However, these emissions are reduced up to 2564 kg CO_2 by on-site electricity generation by PV generator. The emissions associated with the imported electricity from the mains grid in absence of PV are 732 kg CO_2, 3.17 kg SO_x and 1.55 kg NO_x per year.

Table III gives the amount of net profit earned in present microgrid system. The payback period and LCoE are calculated 12 years and ₹ 8.5 respectively. The net electricity units sold to grid after payback period are 95667 kWh (considering the total life span of system is 25 years). Therefore, total profit earned in present study is ₹ 813169. For simplicity of the earned profit calculation, the electricity tariff of exported energy to grid is considered equivalent to the LCoE.

Table II ANNUAL DC MICROGRID PERFORMANCE

Load requirement	
Total load consumption	5215 kWh per year
Flat plate solar photovoltaic	
Rated Capacity	7.5 kW
Mean output	34.5 kWh/day
Total production	12574 kWh/year
Grid	
Annual energy sold	8517 kWh
Annual energy purchased	1158 kWh
Bidirectional Inverter losses	
Rated capacity	4.5 kW
Inverter hours of operation	3708 hrs/year
Rectifier hours of operation	5052 hrs/year
Inverter losses	448 kWh/year
Rectifier losses	58 kWh/year
Emissions (due to energy imported from grid)	
Carbon dioxide	732 kg/year
Sulfur dioxide	3.17 kg/year
Nitrogen oxides	1.55 kg/year
Reduction in Emissions (Energy exported to grid)	
Reduction in Carbon dioxide	2564 kg/year

Table III. EVALUATION OF EARNED PROFIT

Parameters	**Value**
Payback period	≈ 12 years
Net energy exported to the grid per year	7359 kWh
System Lifetime	25 years
Levelized cost of electricity (LCoE)	₹ 8.5
Years of profit	13
Tariff*	₹ 8.5
Earned profit	≈ ₹ 813169

* considering per unit cost of electricity equivalent to LCoE

IV. CONCLUSION

Present study shows the application of DC microgrid based on the PV generator to meet the load demand of a typical school. Energy storage system is eliminated by incorporating the interface with the mains grid. Performance analysis of such system throughout the year shows the variation in the load demand and PV electricity production that imposes the need of electricity import and export for maximizing the system performance not only energetic but economic point of view also. PV electricity production is found to be maximum for summer months and decreases significantly during winter months for Roorkee, India location. Load profile of such typical school found to be maximum during the summer months and decrease considerably in winter months, however during vacations seasons load demand is very less. Therefore, this study shows that the application of PV generator to meet such school load demand has significant potential to earn the profit due to varying load profiles especially in vacations and winter seasons. The application of microgrid shows the reduction in the emission by 2564 kg of CO_2 per year. The calculated payback period is 12 years. There are significant time (of 13 years) to meet the load demand at free of cost and for earning the profit in case of excess power generation. The total earned profit for the studied DC system is ≈ ₹ 813169. Such kind of system not only reduce the need of energy storage system but also gives the more efficient and economical solution for schools in countries like India.

ACKNOWLEDGEMENT

Authors are thankful to India-Trento Programme for Advanced Research (ITPAR)-IV project entitled “Sustainable Technologies for Distributed Level Application and Energy Support to Rural Development-II (STAR-II) (Project no: RP03755G)” to carry out this research work.

REFERENCES

[1] S. H. Kulkarni, T. R. Anil, “Status of Rural Electrification in India, Energy Scenario and People's Perception of Renewable Energy Technologies,” Strategic Planning for Energy and the Environment, Vol. 35, 2015, pp. 41-72.

[2] http://www.ddugjy.gov.in/portal/index.jsp.

[3] https://mnre.gov.in/file-manager/UserFiles/draft-jnnsmpd-2.pdf.

[4] https://mnre.gov.in/file-manager/akshay-urja/june-2017/Images/12-16.pdf.

[5] R. Sabzehgar, "A review of AC/DC microgrid-developments, technologies, and challenges," 2015 IEEE Green Energy and Systems Conference (IGESC), Long Beach, CA, 2015, pp. 11-17.

[6] D. Fregosi, S. Ravula, D. Brhlik, J. Saussele, S. Frank, E. Bonnema, J. Scheib, and E. Wilson, "A comparative study of DC and AC microgrids in commercial buildings across different climates and operating profiles," 2015 IEEE First International Conference on DC Microgrids (ICDCM), Atlanta, GA, 2015, pp. 159-164.

[7] K. Engelen, E. L. Shun, P. Vermeyen, I. Pardon, D. J. Driesen, and R. Belmans, “The Feasibility of Small-Scale Residential DC Distribution Systems,” IEEE Industrial Electronics IECON 2006, 32nd Annual Conference, 6–10 Nov 2006, pp. 2618-2623.

[8] S. Anand and B. G. Fernandes, "Optimal voltage level for DC microgrids," IECON 2010 - 36th Annual Conference on IEEE Industrial Electronics Society, Glendale, AZ, 2010, pp. 3034-3039.

[9] S. Dahale, A. Das, N. M. Pindoriya and S. Rajendran, "An overview of DC-DC converter topologies and controls in DC microgrid," 2017 7th International Conference on Power Systems (ICPS), Pune, 2017, pp. 410-415.

[10] A. Gupta, S. Doolla and K. Chatterjee, "Hybrid AC–DC Microgrid: Systematic Evaluation of Control Strategies," in IEEE Transactions on Smart Grid, vol. 9, no. 4, pp. 3830-3843, July 2018.

[11] H. Shahinzadeh, M. Moazzami, S. H. Fathi and G. B. Gharehpetian, "Optimal sizing and energy management of a grid-connected microgrid using HOMER software," 2016 Smart Grids Conference (SGC), Kerman, 2016, pp. 1-6.

[12] K. M. Krishna, "Optimization analysis of Microgrid using HOMER — A case study," 2011 Annual IEEE India Conference, Hyderabad, 2011, pp. 1-5.

[13] V.K. Shankar, A. Gopikanna, S. Shankar, G. Rajan and V. Vijayaraghavan, "Intelligent system design optimization with dynamic load profile for a stand-alone rural Indian microgrid," 2018 IEEE Texas Power and Energy Conference (TPEC), College Station, TX, 2018, pp. 1-6.

[14] S.K. Sahoo, A. K. Sinha and N. K. Kishore, "Control Techniques in AC, DC, and Hybrid AC–DC Microgrid: A Review," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 6, no. 2, pp. 738-759, June 2018.

[15] https://www.homerenergy.com/.

[16] https://www.nrel.gov/international/ra_india.html.

[17]https://eosweb.larc.nasa.gov/PRODOCS/sse/table_sse.html.