Analysis of a Microgrid having Solar System with Maximum Power Point Tracking and Battery Energy System

Jewel Dey
Institute of Energy Technology
Chittagong University of Engineering and Technology
Chittagong-4349, Bangladesh
jeweldeyeee@yahoo.com

Nur Mohammad
Department of Electrical and Electronics Engineering
Chittagong University of Engineering and Technology
Chittagong-4349, Bangladesh
nur.mohammad@cuet.ac.bd

Md. Tazul Islam
Department of Mechanical Engineering
Chittagong University of Engineering and Technology
Chittagong-4349, Bangladesh
mdtazul.islam@cuet.ac.bd

***Abstract*— This paper provides circuit modelling of a microgrid that has a solar power system with maximum power point tracking and a battery energy system. The maximum power of the photovoltaic panel is tracked by using the Incremental Conductance MPPT set of rules. A Boost converter is used to adjust the voltage level corresponding to the MPPT. The required adjustable duty cycle switches the converter. The battery is employed as memory means that's connected to the bidirectional DC-DC power converter. The necessary change of the converter should be exhausted the way that it charges or discharges the battery relying upon the load profile. This model gives benchmark sizing of the PV module and battery energy storage for standalone microgrid PV operation. The model able to harness the maximum power with minimal oscillations, decreases the system losses in the energy management system and increases overall efficiency.**

Keywords— Maximum Power Point Tracking (MPPT), Boost converter, Bidirectional DC-DC converter, Micro-Grid, Incremental Conductance algorithm, Solar panel.

I. Introduction

The reduction of fossil fuels, the rise in prices, and the effect on nature while making use of fossil fuels to generate electricity have forced industrialists. The scientists and the public are now pretty much concerned to use natural sources like as wind, biomass, hydropower, and solar power. Advantages of solar power generation have less maintenance cost and no fuel cost in production, and fully environmentally sociable [1]. The European nations are leading in the solar strength era. Now in Asia, the Solar farm project in India which has 2,700 MW capacity, is one of the major PV power generation farms. Recently, in Bangladesh at Bagerhat has the largest solar PV plant which has a 130 MW installed capacity in December 2021. The top-ranked photovoltaic (PV) installer is now in China with a total capacity of 205 (GW) at the end of 2020.

Recently, in the fourth industrialization, small mills and power facilities use power electronics to control and optimize the efficient flow of energy within the plants. The non-renewable electricity resources with those plants are also expeditiously accustomed to come across the rise in increasing load demand profile. Using mini and microgrids integrated with renewable energy systems as a potential power resource has become a green opportunity to meet the load demand sustainably. Because renewable power is the greatest and most inexpensive supply and free of cost, it can be used freely to generate power when integrated to the excising power system. This first-ranked renewable resource of electricity has numerous advantages like not polluting the nature or not damaging the wooded area landmarks. Nonetheless, the energy harness is surely free, there is no need of renovation, there are a couple of different scopes to use of these resources together with water heating, and house heating, extensively utilized in much greater packages [2].

The primary concern is to design an appropriate electricity utility system connected with such a microgrid grid. One of the main reasons is that photovoltaic renewable power supply is extremely fluctuating, and restoring the intermediate circuit voltage profile to a constant value is one of the main issues. Specifically, the change of load demand and power delivery with regulated voltage margin is quite difficult. The actual implication of the renewable resources with the help of the interim DC-DC converter to the utility grid is an essential problem that has been addressed in several papers [3].

To the best of our knowledge, in the last couple of years, MPPT algorithms and control techniques to be used for microgrids have not been enormously explored except in [11], [12], [17], [20]. The authors investigate the DC microgrid system which is depend on solar PV, permanent magnet synchronous generator, battery energy storage systems [13]. The load is assumed as in islanded using MPPT. The authors in [14] [18], explore small scale energy system with wind energy. They investigate micro grid-side converter feasibility. The authors in [15], explore a low-end microcontroller and closed-loop stabilization in MPPT. The authors in [18] – [27] investigate different types of energy conversion topologies with different types of renewable power plants in smart power system grid for optimal operation. Several emerging converters for this purpose have been explored in [28] – [33]. This document exclusively provides the designing microgrid energy management system with MPPT aiming to fully harness the output power of the PV array. In the model, the battery storage system is responsible to maintain a healthy and reliable voltage level. The significance of the battery unit is to make sure wherever the available energy from PV is fed to the grid or absorbed by the storage for later use to load at peak demand hours.

II. GRID-CONNECTED MICROGRID SYSTEM

This section discusses the circuit and network topology standard which is used for the proposed microgrid system. The system consists of the battery energy storage and the photovoltaic array that is linked to bus bar which is a DC link and microgrid system. A green set of rules is applied to obtain maximum performance through interactive inverter. Photovoltaic array is linked via enhanced converter that are applied for meet the goal to supply it by the way of MPPT algorithm. Battery storage attaches with the assist of bi-directional way, which could both rate for the battery via soaking up power from microgrid or discharge condition battery by using injecting to strength into a microgrid. For the following, a bi-directional converter is needed, and the switching must be done in such a way that the battery is either charged or discharged depending on the load status. We know that the photovoltaic solar energy is a renewable energy source and battery is storage for energy exchange which is attached with the bus bar. The battery and bus bar are attached to the converter [4] – [5]. Fig.1 is the proposed schematic diagram of the PV solar system having MPPT that is connected to the grid.

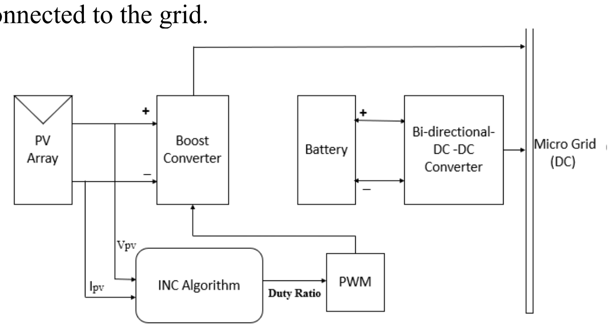

Fig. 1. Schematic diagram of grid-connected system

A. *Modelling and Analysis of PV cell*

The PV cell in the panel uses the photovoltaic effect to transform solar energy into electrical energy. We have used off-the-shelf Simulink software to model the solar PV cell, connected them to make panel. The Simulink block is used to implement and analyze the model, a version of the photovoltaic panel as listed in Table I.

B. *Equivalent circuit of PV cell*

The movement of electrons and holes due to the incident light, known as photons, is symbolized by the symbol I_{ph} in the equivalent circuit of the photovoltaic cell. A diode current runs parallel to the current source defined by I_d. A series resistance R_s and a shunt resistance R_{sh} denotes the semiconductor's metallic contacts and the cutting-edge leakage caused by impurities in the junction diode of the equivalent model respectively. The electrical equivalent circuit of a PV cell is shown in Figure 2. [21].

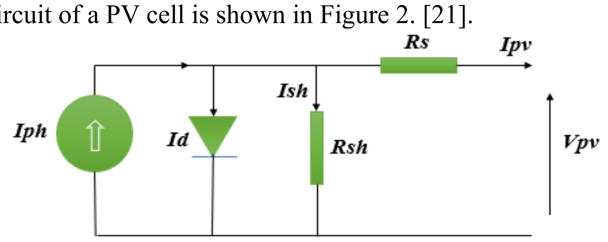

Fig. 2. Electrical Equivalent of a PV cell.

The necessary parameters are taken from a commercially available solar panel which is used for microgrid is shown in Fig. 3. It represents the current-voltage and power-voltage characteristics graph of the PV module. Table 1 listed the necessary parameters and their values.

TABLE I VAIUES OF PV CELL PARAMETER

Some of the key parameter	VALUE
Maximum Power capacity	213.15 W
The voltage at maximum power	32.46V
Current at maximum power	15.7A
Open circuit voltage (Voc)	36.3V
Short-circuit current (Isc)	7..84A
The voltage at maximum power point (Vmp)	29V
Current at maximum power point (Imp)	7.35A
Temperature coefficient of Voc(%deg.C)	-0.36099
Temperature coefficient of Isc(%deg.C)	0.102

Rely on the circuit shown for the PV panel in Fig. 2, the following equation can be used to determine the PV current.

$$i_{pv} = n_p I_{ph} - n_p I_s (\exp [\frac{q(Vpv+Rsipv)}{kTA}] \quad (1)$$

$$\frac{Vpv+ipvRs}{Rsh} \quad (1)$$

The saturation current in this case is I, while the current produced by the sun light is I_{ph}. The following terms are used to represent the following quantities: cell temperature is represented by (T), ideal factor (A), electron charge (q), number of parallel cells (np), shunt resistance (R_{sh}), Boltzmann constant (K), and series resistance (R_s), accordingly.

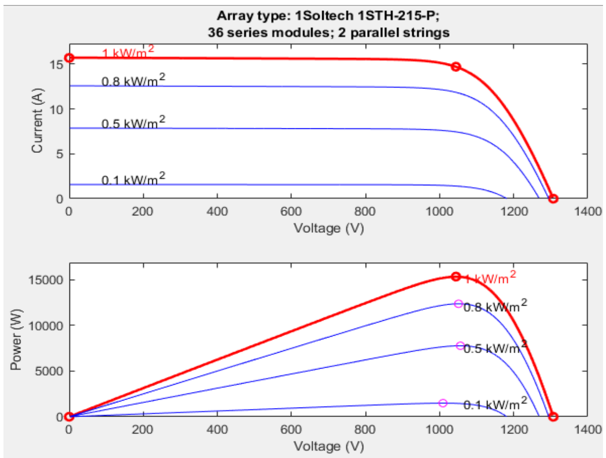

Fig. 3. Current-Voltage and Power-Voltage graph of the module.

The equation of light-generated current is given below:

$$I_{ph} = G(I_{sc} + K_I(T-T_r)) \quad (2)$$

Where short-circuit current is denoted by I_{sc} at 1000W/m^2 and 25 ◦C. The short-circuits current temperature of cell coefficient (K_I), cell reference temperature (T_r) and irradiation (G) in kW/m^2 are denoted respectively. The saturation current of PV cell through cell temperature:

$$I_s = I_{rs} (\frac{T}{Tr})^3 \exp[qE_g/kA((T-T_r) \div TT_r)] \quad (3)$$

Defining the open-circuit voltage by V_{oc}, the band-gap energy is E_g, and the reverse saturation current I_{rs} is given by eq. (4)

$$I_{rs} = Isc \div \exp [qV_{oc} \div n_s kAT] - 1 \quad (4)$$

III. MPPT ALGORITHM USING INCREMENTAL CONDUCTANCE

Due to the low cost and simplicity, the incremental conductance methodology is used as MPPT algorithm in the proposed solar system. The slope of the power–voltage curve of a solar panel is determined by the following equations:

$$\frac{dP}{dV} = 0 \tag{5}$$

Here, the evaluate equation:

$$\frac{dP}{dV} = \frac{d(V.I)}{dV} = V\frac{dI}{dV} + I\frac{dV}{dI} = V\frac{dI}{dV} + I \tag{6}$$

Which indicates that

$$\frac{dP}{dV} = 0\ ,\ \frac{dI}{dV} + \frac{I}{V} = 0 \tag{7}$$

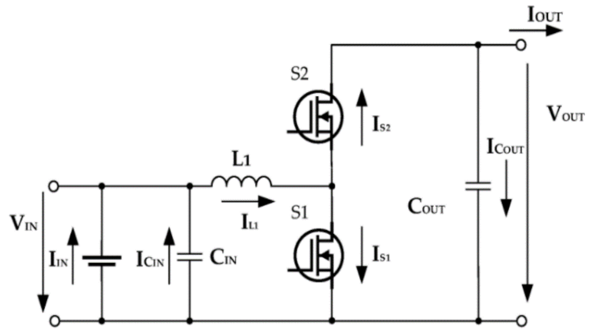

Fig. 5. DC-DC boost converter circuit

The panel's conductance value (I/V) and incremental conductance value (dI/dV) are key input parameters measured using the Incremental Conductance algorithm. The voltage V(k) and current I(k) are sampled for every k step. Fig. 4 better illustrates the incremental conductance MPPT algorithm.

$$\frac{dI}{dV} = -\frac{I}{V} \tag{8}$$

$$\frac{dI}{dV} > 0, -\frac{I}{V} > 0 \tag{9}$$

$$\frac{dI}{dV} < 0, -\frac{I}{V} < 0 \tag{10}$$

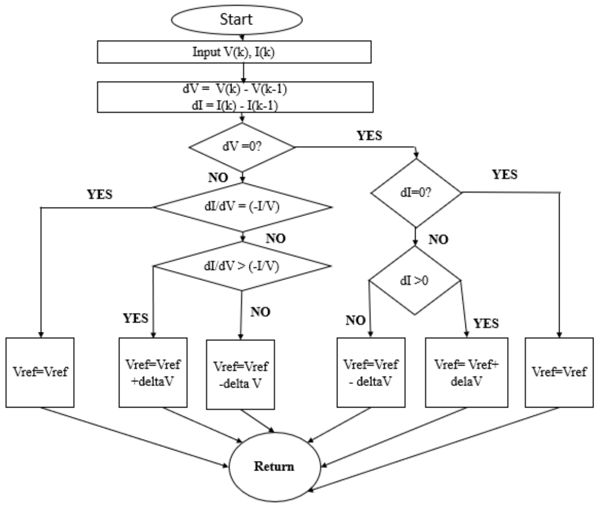

Fig. 4. Flowchart of Incremental Conductance MPPT Algorithm

A. DC–DC Boost converter

The DC-DC boost converter presented in Fig. 5 takes into account the following circuit elements. A capacitor, a MOSFET transistor, an ultrafast diode, an inductor, and resistors are the components of the Boost converter under consideration. The MPPT-based controller generates a pulse width modulation signal that controls the performances of the converter [8], [9].

B. Buck-Boost Converter and Battery Charge Condition

The buck-boost converter is highly supportive in actual battery-powered applications because of its decreasing and increasing voltage level shifting, it may function as either a buck converter or a boost converter, dependent on the switch used to activate the converter. When performing a step-down or buck operation, energy remain same while voltage profile shifts from the high voltage to the low voltage.

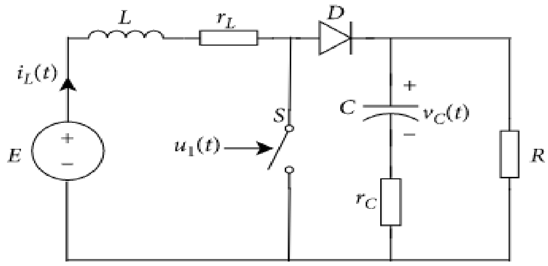

Fig. 6. Bidirectional DC-DC converter circuit diagram

On the other hand, when performing a step-up or boost operation, energy still remain same however, the output voltage increases considerably. By picking the switch to either charge or discharge the energy storage battery, the power flow can be controlled [10]. The circuit diagram for a bidirectional converter is best depicted in Fig. 6.

$$(V_{Bus} - V_{Battery})\,T_{on} = V_{Battery}(T - T_{on}) \tag{11}$$

$$D_1 = \frac{VBattery}{VBus} \tag{12}$$

$$D_1 = \frac{Ton}{T} \tag{13}$$

Inductance (L) is expressed in equation,

$$L = \frac{(VBus - VBattery)D1}{del\ I * f} \tag{14}$$

Capacitance is expressed in equation,

$$C = \frac{del\ I}{8 * del\ V * f} \tag{15}$$

The ripple may arise for insignificant estimation of inductor which is 20–40% of the output current. The necessary equations are used to determine the boost converter's parameters. The setting that results in the lowest current and voltage ripple is chosen. Basically, in primary running mode is triggered when the energy generated through the renewable system is comparatively less than that of the demanded by means of the aggregated load profile. For simplification, we have considered resistive load. If the solar power, P_{PV} less than the load, P_{load} and the battery system is likewise significantly discharged then the entire microgrid system has to shut down. The Boost mood is initiated, if the solar power P_{PV} is less than P_{load} however the battery is charged and is likewise able to supply electricity. Hence energy storage affords backup the system together with the PV output as long as the storage do not totally deplete. The Buck mood is activated, while the solar power, P_{PV} is greater than load, P_{load} and the battery is not in a completely charged state. Throughout this operation, the solar PV panels not only provide electricity to the load but furthermore the surplus energy harnessed by the solar PV are used to charge the battery energy storage for later use. For the duration of this mode of operation, the solar PV panels supply power to the load below most power point enabled manage and it is also ensured that the battery storages keep itself in totally charged condition with steady charging so that that the battery energy storages able to avoid self-discharge.

IV. Simulation and Results

For the purpose of evaluating overall performance, the controller regulate the battery power for the microgrid. The PV system model has been successfully simulated in the Simulink off-the-shelf environment. The ordinary differential equation which is a changeable step and solver was constructed for use with the system model. The sampling time for each pattern in the discrete simulation is set to 1 micro second. The model's total performance evaluation is broken down into the three areas namely MPPT tracking performance, battery charging and discharging performance, and electricity delivery to microgrid as described in the following sections.

The PV system with MPPT based Incremental Conductance Algorithm and Battery storage use the bi-directional converter to take a look at the output below diverse modes of operations. Fig.7 and Fig.8 respectively present the MPPT algorithm simulation model of photovoltaic system with battery storage using bidirectional converter.

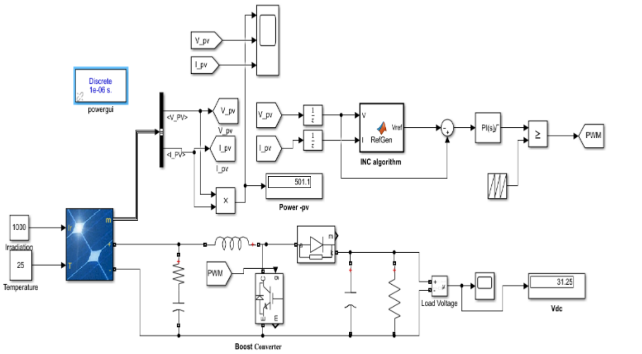

Fig. 7. The Simulink model MPPT base incremental conductance algorithm

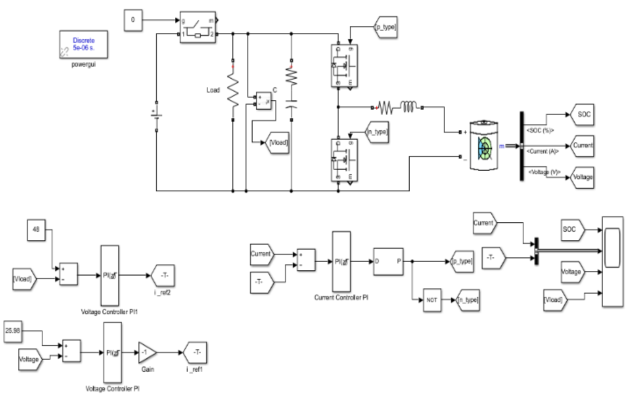

Fig. 8. The Simulation model of Photovoltaic system with Battery storage.

The system is implemented for diverse scenario and the results acquired from the simulation are analyzed and mentioned in this section. In this system, the ambient temperature (Tc) and solar irradiation stage (G) of the solar PV module are given as Tc=25C, G=1000 W/m^2. The solar panel model is provided in Table I. After the simulation by using incremental conductance base algorithm, the power is found to be 501.W, the current is 15.7A and the voltage is 32.46V The Photovoltaic system effectively delivered power to the microgrid. Fig. 9 is representation of the current, voltage and power of photovoltaic system. Voltage in the Boost converter terminal is up to 31V. The voltage profile is given below in Fig.10.

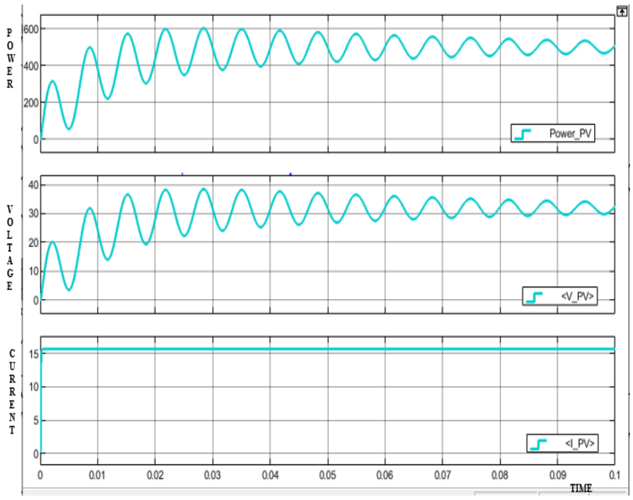

Fig. 9. Power, Voltage and Current supply into microgrid.

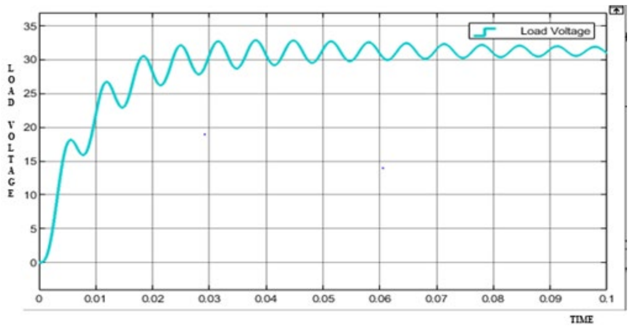

Fig. 10. Voltage measurement of the boost converter.

Bi-directional converters through charging stage of battery is shown. The output increases when the initial stage of charge (SOC) is increased. At different battery charging stage which are (-5, -15 and -10) as shown below in Fig.11. In the result, when the battery charged stage is decreased, voltage is increased and battery charged stage is increased, the voltage is decreased. When battery is charging the voltage is increased, the charged current must be decreased.

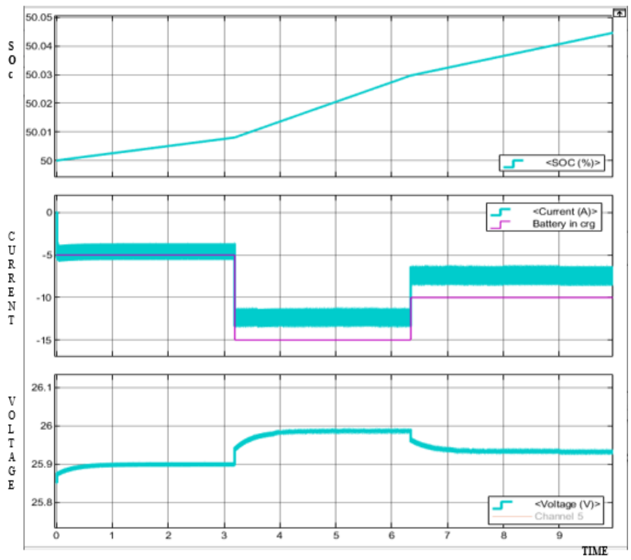

Fig. 11. Result of SOC, Voltage and Current in Battery Charging Stage.

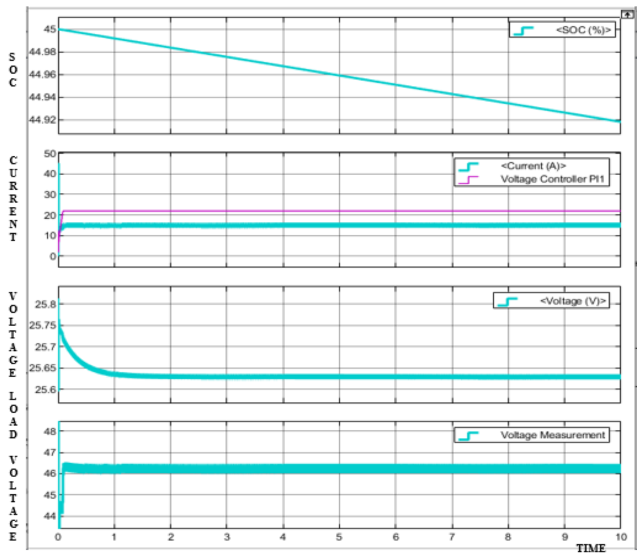

Fig. 12. Result of SOC, Voltage and Current in Battery Discharging Stage.

In the battery discharged state, the SOC is decreased at load voltage at around 48V, while the battery current is in positive mood. At constant voltage, Power is decreased at a constant rate. The result of SOC, Load Voltage, Voltage and Current in Battery Discharging Stage is given in Fig.12.

V. Conclusion

Analysis of a microgrid having solar system with maximum power point tracking and battery energy system has been successfully designed and simulated in this research work. The MPPT Incremental Conductance tracking algorithm using Boost converter that increases up voltage of the PV output which always track the maximum power point. The battery rate regulator of MPPT is successful to charge a 24 V lead-acid battery. A tracing of the maximal energy from photovoltaic array is accounted to be 300W. This energy is supplied to the microgrid. Adjustable charging strategy is performed in four-stage which successfully overcome any deviations and fluctuations. Proposed solar power microgrid model can be implemented to provide quality power to the load, especially in rural area of Bangladesh. The simulation results better prove its compatibility for real-world application to harness intermittent solar PV power. The effectiveness of the model is verified, the model accurately and quickly tracks the MPP with minimal oscillations, that reduces losses of the energy in the microgrid and increases overall yield.

References

[1] S. S. Mohammed and D. Devaraj, "Simulation of Incremental Conductance MPPT based two phase interleaved boost converter using MATLAB/Simulink," *2015 IEEE International Conference on Electrical, Computer and Communication Technologies* (ICECCT), 2015, pp. 1-6, doi: 10.1109/ICECCT.2015.7225987.

[2] K. Venkateswarlu and J. Krishna Kishore, "Modeling and simulation of micro grid system based on renewable power generation units by using multilevel converter,'' *in International Journal of Engineering Research & Technology* (IJERT), ISSN: 2278-0181, Vol. 1 Issue 6, August – 2012.

[3] Dinanath Prasad, Narendra Kumar, Rakhi Sharma," Modeling and Simulation of Microgrid Solar Photovoltaic System with Energy Storage" *2nd IEEE International conference on power Electronics, Intelligent Control and Energy systems* (ICPEICES-22018)

[4] Irvin J. Balaguer, Qin Lei, Shuitao Yang and Athena Supatti, "Control for grid-connected and intentional islanding operations of distributed power generation," *IEEE transactions on industrial electronics*, vol. 58, no. 1, January 2011.

[5] Amir Khaledian and Masoud Aliakbar Golkar, "Analysis of droop control method in an autonomous microgrid," *Journal of Applied Research and Technology* 15 (2017) 371–377.

[6] GUIZA Dhaouadi, OUNNAS Djamel, SOUFI Youcef, CHENIKHE Salah" Implementation of Incremental Conductance Based MPPT Algorithm for Photovoltaic System" *The 4th International Conference on Power Electronics and their Applications* (ICPEA), 25-27 September 2019, Elazig, Turkey

[7] T. Radjai, , L.Rahmani, S.Mekhilef and J. P Gaubert, " Implementation of a modified incremental conductance MPPT algorithm with direct control based on a fuzzy duty cycle change estimator using dSPACE," *Solar Energy*, vol. 110, pp. 325–337, 2014.

[8] M. Adly, and K. Strunz, " Efficient Digital Control for MPP Tracking and Output Voltage Regulation of Partially Shaded PV Modules in DC Bus and DC Microgrid Systems," *IEEE Transactions on Power Electronics*, vol. 34.7, pp. 6309–6319, 2018.

[9] S. Kouro, J. I. Leon, D. Vinnikov, and L. G. Franquelo, "Grid-connected photovoltaic systems: An overview of recent research and emerging PV converter technology," *IEEE Industrial Electronics Magazine*, vol. 9.1, pp. 47–61, 2015.

[10] Nupur Saxena, Ikhlaq Hussain, Member, Bhim Singh and A. L. Vyas, "Implementation of grid integrated pv-battery system for residential and electrical vehicle applications," *IEEE transactions on industrial electronics*, vol. 65.8, Aug. 2018.

[11] M. A. Islam, A. B. Talukdar, N. Mohammad and P. K. S. Khan, "Maximum power point tracking of photovoltaic arrays in Matlab using fuzzy logic controller," *2010 Annual IEEE India Conference* (INDICON), 2010, pp. 1-4, doi: 10.1109/INDCON.2010.5712680.

[12] K. Tiwari, S. Seema and B. Singh, "Hybrid Generation Based Utility Grid Connected Microgrid using SOGI-PLL-WTPF Control Technique," 2021 IEEE Industry Applications Society Annual Meeting (IAS), 2021, pp. 1-6, doi: 10.1109/IAS48185.2021.9677078.

[13] A. Islam, O. Das and N. Mohammad, "Optimized Energy Generation and Power Flow Model to Minimize Power System Operation Cost," *2021 5th International Conference on Electrical Information and*

Communication Technology (EICT), 2021, pp. 1-6, doi: 10.1109/EICT54103.2021.9733542.

[14] S. M. Salam, N. Mohammad and F. Hossain, "A new approach to Analysis the Impact of Demand Side Management for Temperature Control Load Consideration in a Test Bus System," 2021 5th International Conference on Electrical Information and Communication Technology (EICT), 2021, pp. 1-6, doi: 10.1109/EICT54103.2021.9733717.

[15] S. Bhattacharyya, S. Puchalapalli and B. Singh, "Battery Management and Operation of a Wind-PV Based Microgrid," *2020 IEEE International Conference on Computing, Power and Communication Technologies* (GUCON), 2020, pp. 423-429, doi: 10.1109/GUCON48875.2020.9231116.

[16] Mohammad, N. and Mishra, Y. (2018), Coordination of wind generation and demand response to minimise operation cost in day-ahead electricity markets using bi-level optimisation framework. *IET Gener. Transm. Distrib.*, vol. 12, p.p. 3793-3802, doi: 10.1049/iet-gtd.2018.0110.

[17] José-Enrique Hernández-Díez,César-Fernando Méndez-Barrios,Silviu-Iulian Niculescu,Ernesto Bárcenas-Bárcenas" A Current Sensorless Delay–Based Control Scheme for MPPT–Boost Converters in Photovoltaic Systems" *IEEE Access*, vol. 8.21, September 2020.

[18] N. Mohammad and Y. Mishra, "Transactive market clearing model with coordinated integration of large-scale solar PV farms and demand response capable loads," *2017 Australasian Universities Power Engineering Conference* (AUPEC), 2017, pp. 1-6, doi: 10.1109/AUPEC.2017.8282496.

[19] Quamruzzaman, M., Mohammad, N., Matin, M. A., & Alam, M. R. (2016). "Highly efficient maximum power point tracking using DC–DC coupled inductor single-ended primary inductance converter for photovoltaic power systems," *International Journal of Sustainable Energy*, vol. 35.9, p.p 914-932.

[20] Ziqing Xia, Mei Su,Zhangjie Liu,Minghui Zheng,Xin Zhang, Peng Wang," Feasible Power-Flow Solution Analysis of DC Microgrid Considering Distributed Generations Under MPPT Control" *IEEE Transactions on Smart Grid*, vol. 13.1, Jan. 2022.

[21] S. Barua and N. Mohammad, "Optimization-based Energy Management System to Minimize Electricity Bill for Residential Customer," 2021 3rd International Conference on Electrical & Electronic Engineering (ICEEE), Rajshahi, Bangladesh, 2021, pp. 105-108.

[22] S. Nazifa, N. Mohammad, P. Dutta and M. Barua, "Frequency Weighted Finite Control Set MPC of Multilevel Inverter for Controlled Spectrum of Load Current," 2020 2nd International Conference on Sustainable Technologies for Industry 4.0 (STI), Dhaka, Bangladesh, 2020, pp. 1-4. doi: 10.1109/STI50764.2020.9350458.

[23] M. A. Rahman, I. Rahman and N. Mohammad, "Implementing Demand Response in The Residential Energy System to Solve Duck Curve Problem," 2020 2nd International Conference on Advanced Information and Communication Technology (ICAICT), Dhaka, Bangladesh, 2020, pp. 466-470.

[24] M. A. Rahman, I. Rahman and N. Mohammad, "Demand Side Residential Load Management System for Minimizing Energy Consumption Cost and Reducing Peak Demand in Smart Grid," 2020 2nd International Conference on Advanced Information and Communication Technology (ICAICT), Dhaka, Bangladesh, 2020, pp. 376-381.

[25] S. M. Salam and N. Mohammad, "Load Flow Analysis of a Six Bus System for a Bulk Scale Replacement of Conventional Lighting Loads in a Distributed Network," 2020 IEEE Region 10 Symposium (TENSYMP), Dhaka, Bangladesh, 2020, pp. 831-834.

[26] M. A. Islam, N. Hasan and N. Mohammad, "Power System Optimization Model Using Economic Load Dispatch," 2020 IEEE Region 10 Symposium (TENSYMP), Dhaka, Bangladesh, 2020, pp. 469-472, doi: 10.1109/TENSYMP50017.2020.9230967

[27] B. Das, A. M. M. Reza, N. Mohammad and S. H. Razo, "Smart Grid Dynamic Pricing Algorithm for Benefit Maximization of Service Providers and Consumers," 2020 IEEE Region 10 Symposium (TENSYMP), Dhaka, Bangladesh, 2020, pp. 206-209, doi: 10.1109/TENSYMP50017.2020.923070.

[28] A. Belkaid, I. Colak, K. Kayisli, M. Sara and R. Bayindir, "Modeling and Simulation of Polycrystalline Silicon Photovoltaic Cells," *2019 7th International Conference on Smart Grid*, 2019, pp. 155-158, doi: 10.1109/icSmartGrid48354.2019.8990733.

[29] F. Ayadi, I. Colak, I. Garip and H. I. Bulbul, "Impacts of Renewable Energy Resources in Smart Grid," *2020 8th International Conference on Smart Grid*, pp. 183-188, doi: 10.1109/icSmartGrid49881.2020.9144695.

[30] Y. Furukawa, Y. Shibata, H. Eto, I. Colak and F. Kurokawa, "Static Analysis of a Digital Peak Current Mode Control DC–DC Converter Using Current–Frequency Conversion," *in IEEE Transactions on Power Electronics*, vol. 37, no. 7, pp. 7688-7704, July 2022, doi: 10.1109/TPEL.2022.3145811.

[31] O. Guenounou, A. Belkaid, I. Colak, B. Dahhou and F. Chabour, "Optimization of Fuzzy Logic Controller Based Maximum Power Point Tracking Using Hierarchical Genetic Algorithms," 2021 9th International Conference on Smart Grid (icSmartGrid), 2021, pp. 207-211, doi: 10.1109/icSmartGrid52357.2021.9551249.

[32] S. Benhadouga, A. Belkaid, I. Colak, M. Meddad and A. Eddiai, "Experimental Validation of The Sliding Mode Controller to Improve The Efficiency of The MPPT Solar System," 2021 10th International Conference on Renewable Energy Research and Application (ICRERA), 2021, pp. 333-337, doi: 10.1109/ICRERA52334.2021.9598584.

[33] Abu Shufian, N. Mohammad, "Modeling and analysis of cost-effective energy management for integrated microgrids," *Cleaner Engineering and Technology*, vol. 8, Jun. 2022, p.p 100508, doi: 10.1016/j.clet.2022.100508