Renewable Microgrids and EV Charging: Towards Flexible and Sustainable Energy Systems

Laxman Jatav
M. Tech Student
School of Electrical& Electronics Engineering
Scope Golbal Skills University
Bhopal M.P., India
ls784019@gmail.com

Anjana Tripath
Assistant Professor
School of Electrical& Electronics Engineering
Scope Golbal Skills University
Bhopal M.P., India

Balram Yadav
HOD
School of Electrical & Electronics Engineering
Scope Golbal Skills University
Bhopal M.P., India

Abstract: The pressing need to lower greenhouse gas emissions, encourage the use of renewable energy, and assist in the electrification of transportation is causing a rapid change in the global energy environment. In this regard, microgrids powered by renewable energy have become a crucial component of decentralized, robust, and sustainable energy production. Due to the dynamic and expanding demands for charging, the increasing use of electric vehicles (EVs) simultaneously poses a challenge and an opportunity for power systems. Combining electric vehicle charging infrastructure with renewable microgrids presents a viable solution to maximize energy use, lessen reliance on fossil fuels, and maintain environmental sustainability. Significant technological difficulties are brought about by this integration, though, mainly in the areas of load control, energy fluctuation, and grid synchronization. These microgrids offer energy flexibility and dependability in both grid-connected and islanded modes.

Keywords: Greenhouse gas emissions, Fossil fuel reduction, Microgrids, Load control

I. INTRODUCTION

The demand for electricity is steadily increasing due to the increase in inhabitants and industrial development. Energy generated from natural sources such as coal or gas is not consistent with today's energy demand. Since coal (fossil fuel) is cheaply available, an enormous quantity of electrical energy is generated from fossil fuels. Fossil fuels cause significant damage to the environment by liberating carbon dioxide and mercury during energy conversion, which leads to global warming . Sustainable energy sources can be used in power generation to overcome the challenges faced by generating electrical power from fossil fuels.

Dealt with the net generation of electricity from renewable sources which is expected to be equal to coal production by 2040. Nearly half of renewable energy is obtained from wind and solar power. Recent advances lead to renewable energy systems which are low cost. The average cost reduction for Solar Photovoltaic (PV) and shore winds forecast at 40–70% and 10-20 % by 2040. The growing global energy crisis is affected by the depletion of conventional energy sources , and also has the following drawbacks:

- Emission of harmful pollutants
- Carbon dioxide and mercury emissions are anticipated to increase by 35% and 8% by 2020 as the electricity generation is projected to increase.

1.1 PV SYSTEMS IN ENERGY CONVERSION

PV systems can be divided into two basic categories: (1) standalone and (2) grid-connected. Extra batteries are needed in a stand-alone PV system in order to store the extra electricity generated. However, with a GCPVS, the grid serves as an endlessly storing battery. It handles variations in the seasonal load. Without being thrown away, the PV system's excess electrical energy can be kept in the grid. As a result, a GCPVS will be more efficient

Received 24 June 2025, Accepted 3 August 2025

than a standalone PV system. As a result, grid PV systems are preferred over standalone PV systems

The five distinct inverter designs for GCPVS are displayed in Figure 1.1. [6] These include the modular inverter system, the string inverter system, the multi-string inverter system, the centralized inverter system, and the multi-central inverter system. The centralized inverter system's structure is depicted in Figure 1.1a. It is made up of multiple strings of PV panels connected in series with a single inverter. The DC power from the PV panels is converted by the central inverter, which then pumps AC power to the grid. The primary disadvantage of a centralized inverter system is that each solar module does not operate at its maximum power point when there is shade. The structure of the multi-centralized inverter system, which uses DC-DC converters to address the shortcomings of the central inverter system, is depicted in Figure 1.1b.The structure of a string inverter is depicted in Figure 1.1c. PV string is connected to the inverter to construct the structure. PV modules placed in sequence make up a PV string. The string inverter's output typically ranges from 340V to 510V.The structure of a multi-string inverter system is depicted in Figure 1.1d. Some of the PV panels can be taken off the string if DC-DC boost converters are attached to it. This structure is more dependable and saves money.

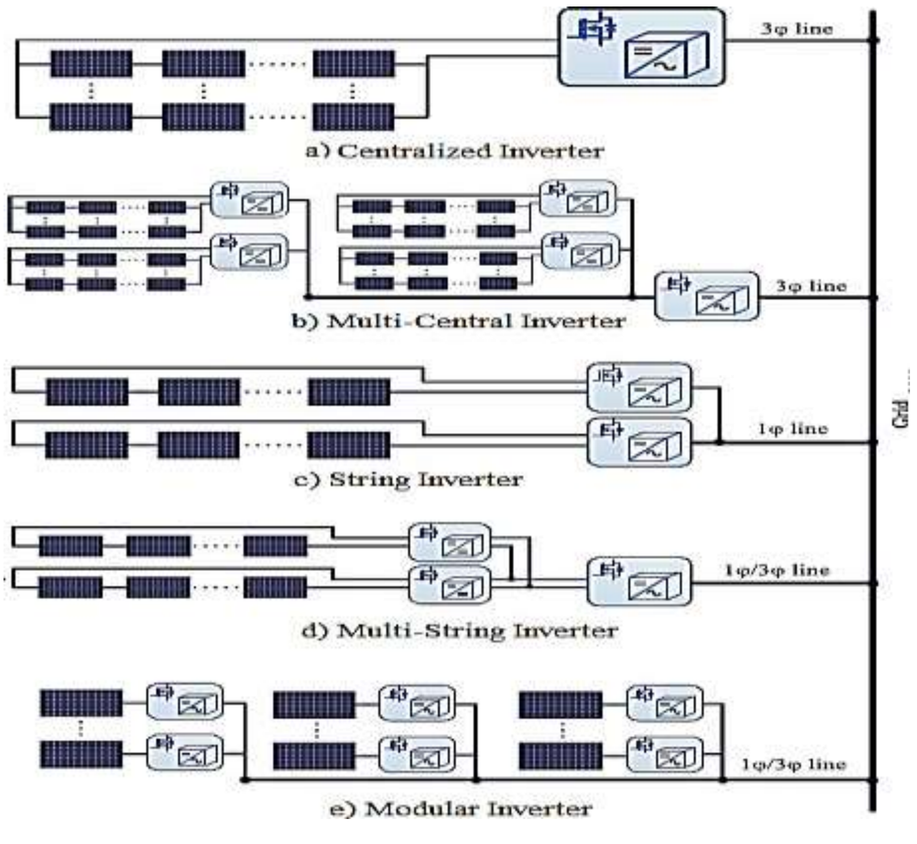

Figure 1.1 Grid Connected PV Topologies

Figure 1.1e shows the structure of a modular inverter. This is also known as micro inverter or module integrated inverter. Because of the compact design of the inverter it can be easily fixed behind the PV module.

II. MODELLING OF PV ARRAY

A photovoltaic system uses one or more solar modules or panels to convert solar energy to electrical energy.

Basically, its components include solar panels, mechanical and electrical connections and means of modifying the electrical output we get.

2.1 Photovoltaic Cell

Any solar PV cell transforms light energy into electricity; wherein a single solar cell produces mW of power. Hence, large number of PV cells is connected in series and parallel fashion to create a module. Further to meet higher power demand, these PV modules are linked in both series and parallel manner to form an array.

2.2 Photovoltaic Module

The voltage generated by a single solar cell is very low, around 0.5V. So, a number of solar cells are connected in both series and parallel connections to achieve the desired output. In case of partial shading, diodes may be needed to avoid reverse current in the array. Good ventilation behind the solar panels are provided to avoid the possibility of less efficiency at high temperatures.

2.3 Photovoltaic Array

Again the power produced by a single module is not sufficient to meet the power demands for most of the practical purposes. PV arrays can use inverters to convert the dc output into ac and use it for motors, lighting and other loads. The modules are connected in series for more voltage rating and then in parallel to meet the current specifications.

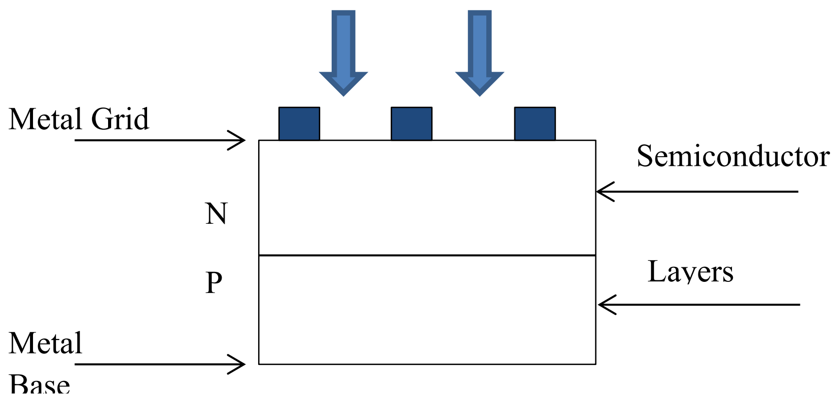

Figure 2.1: Structure of a PV cell

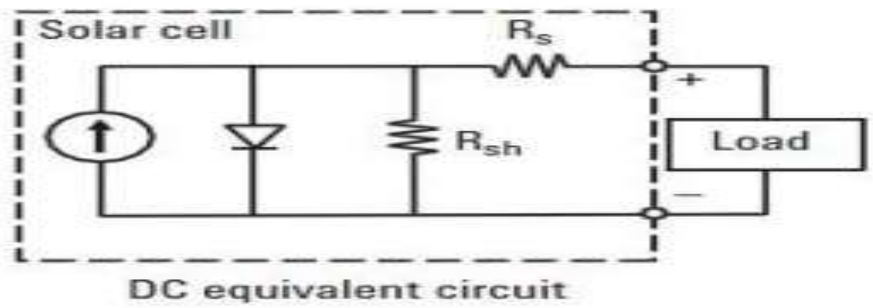

Figure 2.2: Simplified circuit diagram of a solar PV cell

III. MPPT ALGORITHM

3.1 Perturb and Observe

In this method the controller adjusts the voltage from the array and measures power. If the power increases, further adjustments in that direction are tried until power no longer increases. This is called the perturb and observe method and is most common. It is also referred as a hill climbing method, because it depends on the rise of the power against voltage below the maximum power point. Perturb and observe is the most commonly used MPPT method due to its ease of implementation. Perturb and observe method may result in high efficiency

.

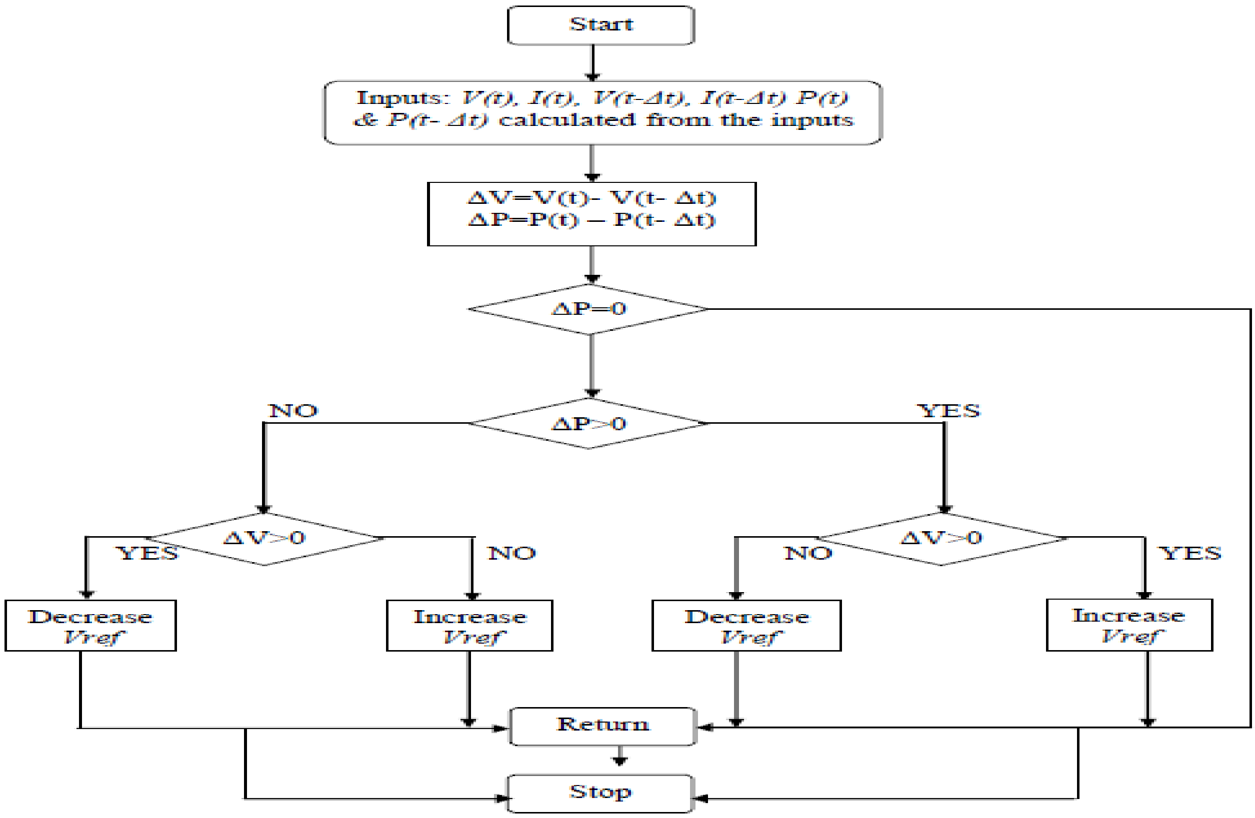

Figure 3.1: Algorithm of perturbation and observation

Figure 3.1 displays the Perturbation & Observation method algorithm. According to the Perturb & Observe algorithm, if a modest increase in the PV panel's operating voltage causes a positive change in power ΔP, the perturbation is in the direction of MPP. It is necessary to adjust the sign of the perturbation supplied if ΔP is negative, as this indicates that the movement is not in the direction of MPP. Figure 3.5 illustrates this. If the power increases, the perturbation should continue in the same direction; if the power falls, the next perturbation should go in the other way. Until the MPP is attained, the procedure is repeated.

Thus, a maximum power point tracker achieves maximum power from the solar PV module. A non-isolated DC-DC converter (step up/ step down) is implemented for conversion of this maximum power to the grid. This converter acts as an interface between the SAPF and the module. The MPPT controller controls the output voltage of the DC-DC converter by regulating the PWM signals applied to the switch of the converter unit

IV. EVOLUTION OF PWM STRATEGIES

The trapezoidal PWM strategy offers several advantages compared to SPWM in terms of easy and fast real-time waveform generation and higher fundamental output voltage. The trapezoidal wave can be obtained from a triangular wave by limiting its magnitude as shown in Figure 4.1. The angle of the flat portion of the trapezoidal wave is given by

$$2\varphi = (1-\sigma)\pi$$

Where σ is called the triangular factor, the waveform becomes a triangular wave when σ =1.

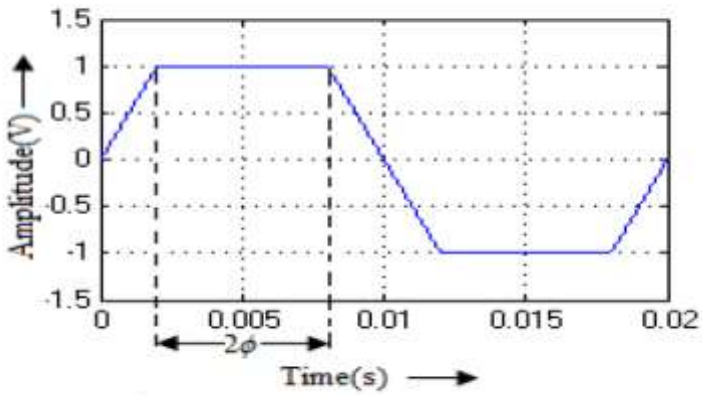

Figure 4.1: Reference waveform of trapezoidal PWM

V. FILTERS

With the advent of renewable energy generation through solar, wind, etc., grid-tied voltage source inverters (VSI) are becoming popular as the power electronic interface. However, due to pulse width modulations (PWM) of the VSI, high frequency switched voltages are generated resulting in distortion of the grid currents. Hence, an inductive (L) filter is generally used to couple it with the grid. However, to reduce cost of copper and magnetic material of L, an LCL filter is more often used. The LCL filter results in relaxing the size of the boost inductor (inverter side) and provides better attenuation of the ripple current. Hence, an LCL filter is commonly used at the inverter output. The ability to use an LCL filter at low switching frequencies, its advantages in filter dimensions compared to traditional "L" and "LC" filters, and its lower voltage drop and improved damping compared to conventional "L" and "LC" filters are the most significant reasons for choosing it.

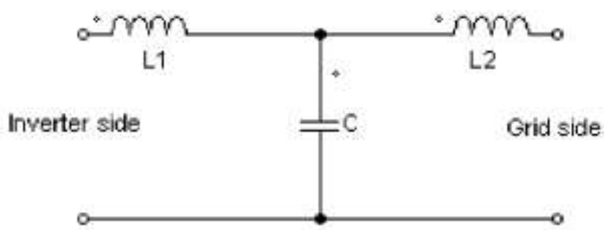

Figure 5.1: An LCL filter

VI. SIMULATION RESULTS

The proposed Microgrid operates in grid-tied or isolated mode. AC sources and loads are connected to AC network, whereas DC sources and loads are connected to DC network. Figure 5.1 shows the three-phase grid voltage and grid current. Which used to connect to AC bus by using LCL filter. This three-phase voltage and current stabilised unity power factor at the grid side and also its have lower harmonics.

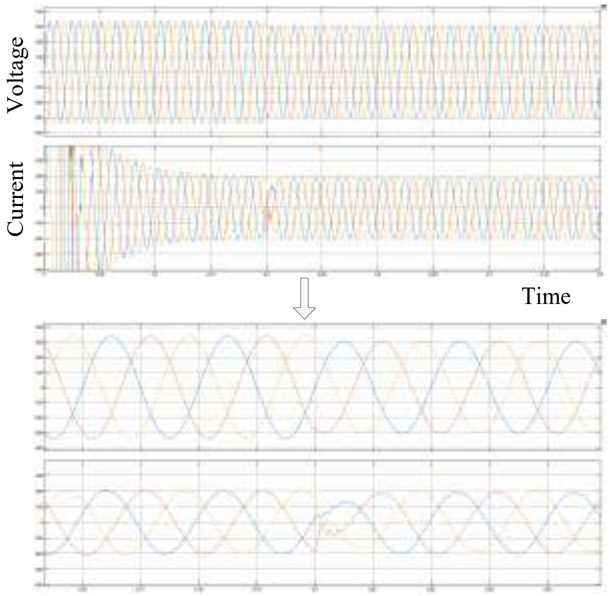

Figure 6.1: Three phase grid voltage and current

By creating some disturbance through grid at time of 0.2 sec it reduces a voltage by 10%. So, it created a sudden disturbance at this time renewable energy sources perform a role so it maintains this voltage to the same condition. In figure 5.1 voltage reduces by 10% but current maintain same peak to peak amplitude.

By the sudden change the grid voltage peak reduces simultaneously for the AC load. By the design of the filter which is perform a specific role in connected with AC and DC bus, load voltage and current are ripple free which is shown in figure 5.2 and also, figure 5.3 shows the inverter current and load current.

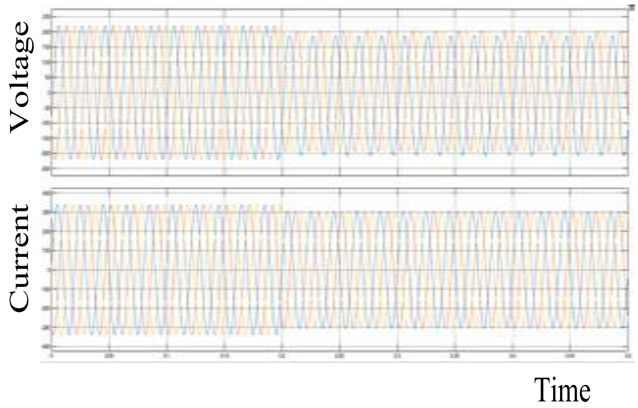

Figure 6.2: Three phase AC load voltage and current

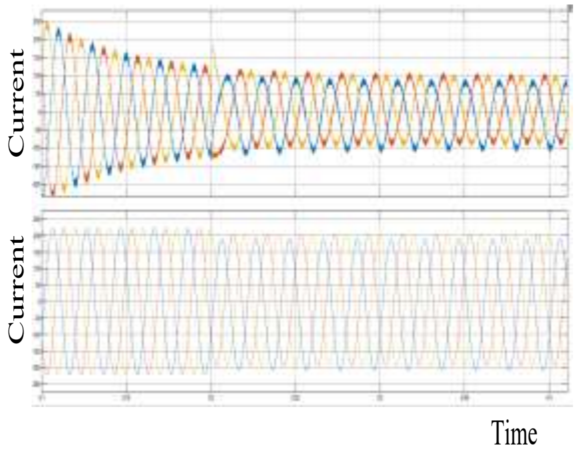

Figure 6.3: Three phase AC inverter current and load current

VII. CONCLUSION

Two significant technological trends have come together as a result of the growing emphasis on clean energy and sustainable mobility around the world: the installation of microgrids powered by renewable energy sources and the quick uptake of electric cars (EVs). Although each area on its own promises to significantly reduce carbon emissions and reliance on fossil fuels, when combined, they provide a potent chance to transform the transportation and energy distribution industries. But there are certain difficulties with this integration.

In order to supply dependable and eco-friendly electricity to nearby towns or facilities, renewable energy-based microgrids use a decentralized approach to power generation, integrating sources such as solar photovoltaics (PV), wind turbines, and energy storage systems. These microgrids need strong grid synchronization when connected to the conventional grid in order to guarantee steady voltage, frequency, and phase alignment with the utility supply. In order to prevent instability, harmonics, or disconnections that could jeopardize the safety and dependability of the entire power system, effective synchronization is essential.

Conflict of Interest: The corresponding author, on behalf of second author, confirms that there are no conflicts of interest to disclose.

Copyright: © 2025 by Laxman Jatav, Anjana Tripath, Balram Yadav Author(s) retain the copyright of their original work while granting publication rights to the journal.

License: This work is licensed under a Creative Commons Attribution 4.0 International License, allowing others to distribute, remix, adapt, and build upon it, even for commercial purposes, with proper attribution. Author(s) are also permitted to post their work in institutional repositories, social media, or other platforms.

REFERENCES:

[1] S. T. Meraj, S. Yu, M. S. Rahman, K. Hasan and H. Trinh, "A Novel Control Strategy for Grid Forming PV Inverter Integrated with Battery Energy Storage System," 2024 2nd International Conference on Power and Renewable Energy Engineering (PREE), Sendai, Japan, 2024, pp. 66-71.

[2] A. Bansal, R. Kumar and A. K. Yadav, "Optimal Energy Management of Grid-Connected Microgrid With EV Charging Stations Using Modified PSO," IEEE Systems Journal, vol. 18, no. 2, pp. 1345-1354, June 2024,

[3] M. Alhajri, M. Al-Sumaiti, A. Mohamed, and M. Salama, "EV Charging Strategies in Renewable-Energy-Penetrated Microgrids: A Review," IEEE Access, vol. 11, pp. 34300–34320, 2023.

[4] N. Sharma and S. Mishra, "A Review on Grid Synchronization Techniques for Renewable Energy Integration," IEEE Transactions on Industrial Electronics, vol. 70, no. 3, pp. 2653–2665, March 2023.

[5] M. M. Amoli, F. A. Rahimi, and M. H. Moradi, "Real-Time Coordination of Microgrids and EVs for Grid Support Using MPC," IEEE Transactions on Smart Grid, vol. 14, no. 1, pp. 812–824, Jan. 2023, doi: 10.1109/TSG.2022.3204994.

[6] S. Tripathi, P. S. Bisen, and A. B. Saxena, "Smart Charging Infrastructure for EVs Using Renewable Microgrid With IoT," IEEE Internet of Things Journal, vol. 10, no. 7, pp. 6231–6242, Apr. 2023, doi: 10.1109/JIOT.2022.3224043.

[7] M. Hossain, T. K. Saha, and N. Mithulananthan, "Frequency Regulation Support Through EV and Microgrid Coordination in Grid-Connected Mode," IEEE Transactions on Smart Grid, vol. 13, no. 6, pp. 4756–4767, Nov. 2022, doi: 10.1109/TSG.2022.3140563.

[8] L. Zhang and H. Sun, "Bidirectional Charging Control of EVs for Renewable-Based Microgrids Using Deep Reinforcement Learning," IEEE Transactions on Sustainable Energy, vol. 13, no. 4, pp. 2152–2164, Oct. 2022.

[9] A. K. Yadav, R. K. Nema, and R. Tiwari, "Synchronization Control Techniques for Grid-Connected Inverters in Renewable Microgrids: A Review," IEEE Access, vol. 10, pp. 10923–10938, 2022.

[10] Jae-Won Chang, Gyu-Sub Lee, Seung-Il Moon, and Pyeong-Ik Hwang, “A Novel Distributed Control Method for Interlinking Converters in an Islanded Hybrid AC/DC Microgrid”, IEEE Transactions on Smart Grid, 2021.

[11] B. Shyam, S. Anand and S. R. Sahoo, "Effect of communication delay on consensus-based secondary controllers in DC microgrid," IEEE Trans. Ind. Electron., vol. 68, no. 4, pp. 3202-3212, Apr. 2021.

[12] J. Chang et al., “A new local control method of interlinking converters to improve global power sharing in an islanded hybrid AC/DC microgrid,” IEEE Trans. Energy Convers., vol. 35, no. 2, pp. 1014–1025, Jun. 2020.

[13] S. Mudaliyar, B. Duggal, and S. Mishra, “Distributed tie-line power flow control of autonomous dc microgrid clusters,” IEEE Trans. Power Elec-tron., vol. 35, no. 10, pp. 11250–11266, Oct. 2020.

[14] G. Lou et al., “Optimal design for distributed secondary voltage control in islanded microgrids: communication topology and controller,” IEEE Trans. Power Syst., vol. 34, no. 2, pp. 968-981, Mar. 2019.

[15] M. Zolfaghari, M. Abedi, and G. B. Gharehpetian, "Power flow control of interconnected AC-DC microgrids in grid-connected hybrid microgrids using modified UIPC," IEEE Trans. Smart Grid, vol. 10, no. 6, pp. 6298–6307, Nov. 2019.

[16] Gupta, S. Doolla, and K. Chatterjee, "Hybrid AC-DC microgrid: systematic evaluation of control strategies," IEEE Trans. Smart Grid, vol. 9, no. 4, pp. 3830-3843, Jul. 2018.

[17] Jin, J. Wang, and P. Wang, “Coordinated secondary control for autonomous hybrid three-port AC/DC/DS microgrid,” CSEE J. Power and Energy Syst., vol. 4, no. 1, pp. 1–10, Mar. 2018.

[18] Dou, D. Yue, J. M. Guerrero, X. Xie, and S. Hu, “Multiagent sys-tembased distributed coordinated control for radial dc microgrid consid-ering transmission time delays,” IEEE Trans. Smart Grid, vol. 8, no. 5, pp. 2370–2381, Sep. 2017.

[19] Dou, D. Yue, Z. Zhang, and J. M. Guerrero, “Hierarchical delayde-pendent distributed coordinated control for dc ring-bus microgrids,” IEEE Access, vol. 5, pp. 10 130–10 140, 2017.

[20] Kadam and A. Shukla, "A Multilevel Transformerless Inverter Employing Ground Connection Between PV Negative Terminal and Grid Neutral Point," in IEEE Transactions on Industrial Electronics, vol. 64, no. 11, pp. 8897-8907, Nov. 2017, doi: 10.1109/TIE.2017.2696460.