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An Overview of Renewable Energy Control Strategies for Grid-Connected Power Converters

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Abstract—Investments in converter-interfaced resources like wind and photovoltaics, energy storage technologies, and electric vehicles are being pushed by the switch to a greener energy mix to tackle climate change. This causes the present conventional electrical system rapidly transforms into a renewable system. The major renewable energy sources are wind and solar and they are powered by non-synchronous generators through converters. Renewable generation is intermittent in nature and converters play a crucial role in handling grid disturbances. The new design and control of converters are very essential at this stage for effectively utilizing them such that these converters can tackle unforeseen events in the grid. This paper provides a complete review of grid-connected converters available in the literature. The different control strategies and their applicability based on the system are discussed in detail. Then, the applicability of the converters for stability improvement is explored.

Keywords: voltage source converters; renewable energy; wind turbines; solar photovoltaic energy; energy storage; electric vehicles; MPC; control; power system stability.

INTRODUCTION

There are several chances due to population expansion and economic progress with the technical advancements of the early 21st century, maintaining economies is difficult. Sustaining and expanding to meet the requirements of an expanding population while planning for the future the climate problem will significantly impact daily life in the near future. Demands investigation into areas that will enable future generations to live sustainably. Today, A significant portion of the electricity is produced using fossil fuel-based generation sources. Moreover, Internal Combustion Engines (ICE), are heavily utilized in the transportation industry and are also a factor in the recently reported historically high carbon dioxide (CO2) emissions levels. Renewable energy is a clean alternative energy source that does not pollute the environment from the standpoint of the power-producing sector. Environmentally friendly products are being pushed in the transportation industry to electric motors should be used in place of the ICEs. the source of energy for electric vehicles (EVs)ESS that uses batteries rather than fossil fuels. But this is not an easy move. Without EVs are recharged as a result of developments in the power sector that favour renewable energy. Generators that run on fossil fuels, would just replace the CO2 source emissions. The infrastructure for charging would also need to be provided by the electrical sector for more electric vehicles.

Converter-interfaced technologies include renewable energy sources, ESSs, and electric vehicles. For instance, modifications to traditional control Structures to allow wind turbine participation have been researched. Grid-Forming (GFM) converters are another topic of growing attention in the sector. A GFM converter is a type of power converter that operates as a voltage source rather than a Grid-Following (GFL) current source, allowing control of renewable energy and energy storage resources. As a result, a GFM converter can produce its own phase angle, frequency, and amplitude. Therefore, GFM converters can increase the frequency stability of power networks. GFM converter technology is still in its infancy, and an increase in the number of studies looking at it is expected in the coming years. Interest in control methods that can increase CIRs' contribution to the stability of the power system has grown in recent years. For instance, in order to allow wind turbine participation, modifications to conventional control structures have been studied. Grid-Forming (GFM) converters are another item of growing industry interest. A GFM power converters converter mode allows for the use of renewable energy sources and rather than as a grid-following resource, energy storage resources should be controlled as a voltage source. Grid following current source (GFL) Afterward, a GFM converter can produce its own phase angle, frequency as well as magnitude.

II. CONTROL METHODS

The Grid Forming Converter technology is still in its infancy. Development stages and an increase in the number of studies looking into it are anticipated in the upcoming years.

A. The management of solar power plants:

This section discusses solar PV farm management. The general characteristics of PV farms are discussed first, including the current stage of development of installed PV capacity and the primary topologies for connecting PV farms to the grid. Then there is a review of the special characteristics of PV farms. Finally, a discussion of the control mechanisms used with the two-stage PV farm DC/DC converters is offered.

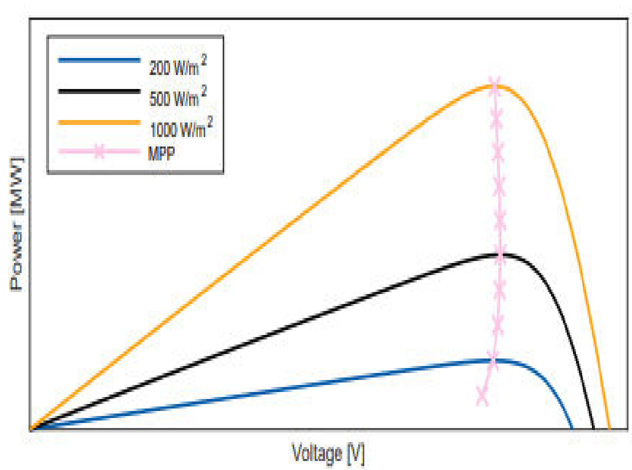

Figure 1 Power characteristics of PV panels as a function of DC voltage and solar irradiance

PV Farm Characteristics and Connection Topologies:

For last two decades, we used the global installed capacity of PV farms. Solar PV capacity has grown dramatically from over 1 GW in 2001 to 707.5 GW in 2020. The key causes for this quick growth include incentive programs, falling costs of mass manufacture of PV panels, and investments in carbon-free power sources.

The main resource in PV farms is solar irradiance, and the availability of this resource depends on the season, day of the week, and amount of cloud cover. The PV panel's design also produces a current output that, when converted into generated power, depends on the availability of the resources and the voltage applied to its terminals.

A PV farm can have two potential topology connections, which affect its operational flexibility.

a. single-stage connections
b. two-stage connections

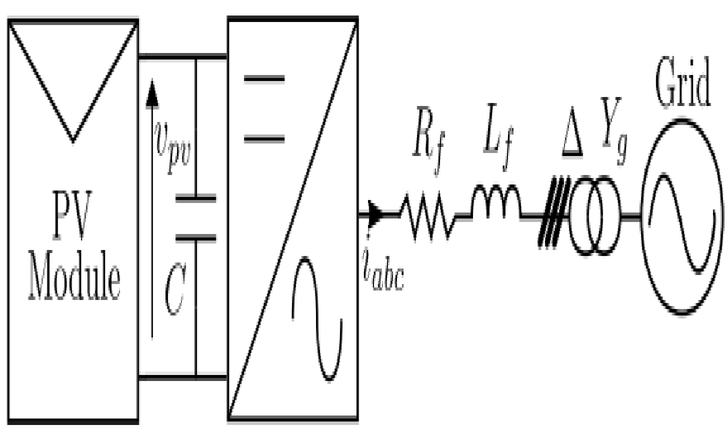

Figure2. A PV module is connected to the electric grid in a single stage.

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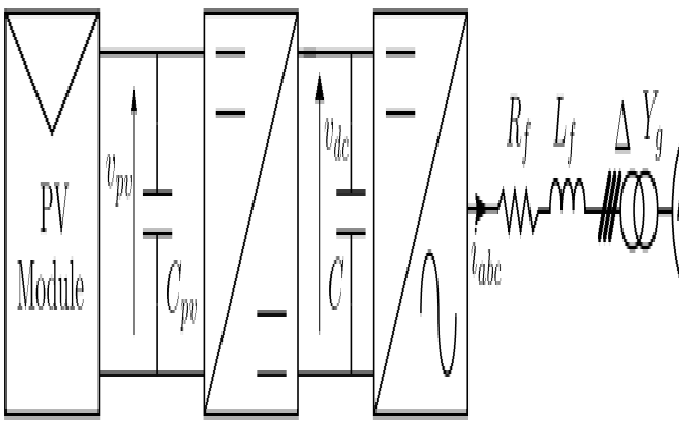

Figure3. A PV module is connected to the electric grid in a two stage.

$$C = \frac{Sconverter}{4\pi f vdc{,}min \Delta vdc} \qquad \textbf{[1]}$$

In a single-stage PV farm, the DC power generated by the PV module is converted into AC power and fed into the grid using a DC/AC converter. The PV module interface with the electrical grid in a dual stage PV farm is made up of two converters, one DC/DC and the other DC/AC.

ESTIMATION OF GRID IMPEDANCE POWER CONVERTERS FOR GRID-FORMING:

A grid-forming Power converter impedance estimation method that has been thoroughly researched. By substituting synchronous generators for these converters, which operate as AC voltage sources, the grid's frequency and voltages are regulated. a grid-forming Power converter impedance estimation method that has been thoroughly researched. The frequency and voltages of the grid are adjusted by replacing synchronous generators for these converters, which function as AC voltage sources. Power electronic converters are grid interfaces for renewable generation systems, energy storage systems, and electric motor drives in modern more-electronics power systems. Grid impedance estimation methods are broadly divided into two categories: online and offline methods.

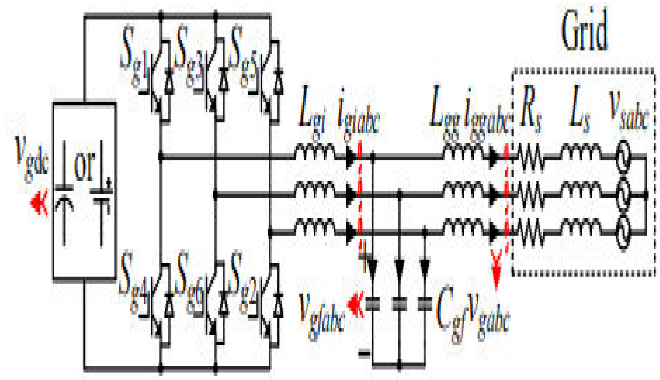

Fig. 4 Diagram of grid-forming power conversion systems.

DC/AC Converter Control for PV Applications:

A mathematical model of the system's major variables is used to design a controller for the DC/AC converters shown in Figures 2 and 3. This section describes how the converter connects to the electrical grid and how the voltage dynamics of its DC bus work. We also go through PV farm control structures. When the Kirchhoff voltage law is applied to the AC side of the DC/AC converter, a mathematical model for the currents is produced.

$$L_f \frac{d}{dt} i_{abC} = -R_f i_{abc} Vc, abc - Vg, abc \qquad \textbf{[2]}$$

Here Lf and Rf are the filter inductance and parasitic resistance, Vc,abc is the voltage synthesized at the converter's terminals, vg,abc is the voltage at the point of connection to the grid, and iabc is the converter current. The designer has a hurdle when using the model provided by (2) as a starting point building a controller. Therefore, one way is to apply the Park Transform given by

$$\begin{bmatrix} x_d \\ x_q \\ x_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos(\theta) & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ \sin(\theta) & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix}$$

[3]

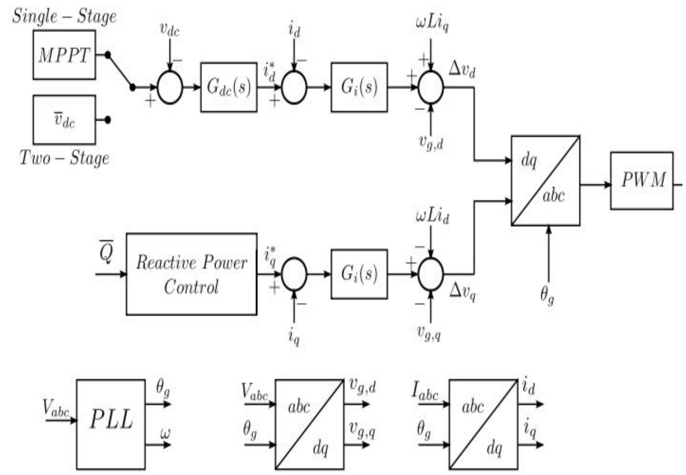

Fig:5 **DC/AC converter control block schematic in the DQ frame**

$$\frac{d}{dt}i_d = \frac{-R_f}{Lf}i_d + \omega iq + \frac{1}{Lf}(v_{c,}d - vg, d)$$

$$\frac{d}{dt}iq = \frac{-R_f}{Lf}i_q - \omega i_d + \frac{1}{Lf}(v_c, q - v_{c,}q)$$

$$\Delta v_d = vc, d - v_{g,d} + \omega L_f iq$$

$$\Delta v_q = vc, q - v_{g,q} + \omega L_f iq$$

$$\frac{d}{dt}i_d = \frac{-R_f}{Lf}i_d + \frac{1}{Lf}\Delta v_d$$

$$\frac{d}{dt}iq = \frac{-R_f}{Lf}i_q + \frac{1}{Lf}vq$$

$$G(s) = \frac{1}{R_f + L_f s}$$

$$Gi(s) = \frac{k_p s + k_i}{s}$$

$$c\frac{dv}{dt}v\,dc = {}^{-3}/_{4}\,id - iv$$

$$G_0(s) = \frac{i\,d^*(s)}{v_{dc}(s)} = \frac{-3}{4C}\frac{1}{s}$$

$$i_q^* = \frac{-2\overline{Q}}{3v_{g,d}}$$

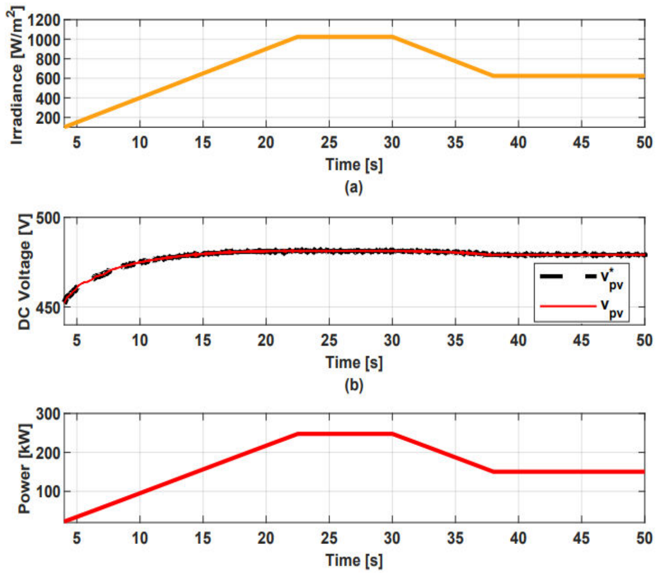

Fig:6 A one-stage PV farm simulation

In PV farms, DC/DC converters are frequently employed. Their primary use is to advance the voltage of a two-stage PV DC/AC converter system to the voltage of the PV array to connect a PV panel to a DC microgrid, or both. In both programs, The PV panel DC voltage is managed by the DC/DC converter. to function within the reference value that an MPPT algorithm provides. This paper focuses on the management of two-stage PV farms' DC/DC boost converters.

As the switch is turned on and off, the system's condition changes. Using averaging theory, one can derive an average model of the system provided by and.

$$\frac{d}{dt}v_{pv} = -\frac{1}{Rc_{Pv}} - \frac{1}{cpv}i_L\frac{1}{Rc_{Pv}}v_{irr}$$

$$\frac{d}{dt}i_L = \frac{1}{L}(v_{pv} - v_{dc}) + \frac{1}{L}v_{dc}d$$

Grid-Connected Energy Storage with Electric Vehicle Control:

Electric vehicles (EV) are now a sustainable transportation choice that emit less noise and pollution than cars with internal combustion engines. EV's operate more effectively and at a lower cost because they are powered by electric motors and batteries. lower running expenses fast charging and advancements in lithium-ion batteries. Technology-related factors have aided in the introduction of EV's.

While an EV is linked to the grid, it can function as a load (when charging) or as a power source.at the cost of more control loops, it can operate more like a grid-connected battery to make a larger contribution to the grid. The goal of the control system when operating the DC/AC converter of an EV is to control the apparent power elements that are exchanged with the electrical grid directly. In PV farms, DC/DC converters are frequently employed. Their primary use is to advance the voltage of a DC/AC converter is used in a two-stage PV system. to the voltage of the PV array to connect a PV panel to a DC microgrid, or both. In both programs, The DC voltage applied to the PV panel is managed by the DC/DC converter. to function within the reference value that an MPPT algorithm provides. This paper focuses on the management of two-stage PV farms' DC/DC boost converters.

	Paper Title	Methodology Adopted	Merits	Demerits
1.	NEW SINGLE PHASE PWM CONVERTER CONTROLLER WITHOUT AC SOURCE VOLTAGE SENSOR	We can employ a step-up chopper between the diode bridge and the filter capacitor to reduce the faults caused by the filter capacitor. When utilizing a step-up chopper, the switching frequency should be raised to reduce dc voltage ripple and system size.However, increasing the switching frequency results in larger switching losses and reduced system efficiency.	1.Simple in structure. 2.Good performance under normal and sudden load change conditions. 3.Power factor is improved.	1. Spikes in voltage 2.Interference with radiofrequency signals.
2	RESONANT CONVERTER NON-LINEAR ANALYSIS AND CONTROL	Resonant converters suppress harmonics and enable zero-voltage switching; they are commonly employed in applications needing great efficiency and minimal EMI noise. A square-wave generator and a resonant circuit comprise a resonant converter. Power density, efficiency, reliability, and other performance characteristics of converters are increased using zero voltage and zero current switching approaches.	1.High efficiency 2. High energy density 3.Electrical isolation wide output ranges 4.High operation frequency.	1.Limited frequency 2.High EMI 3.High switching losses 4.Large size 5.Heavy weight.
3	ESTIMATION OF GRID IMPEDANCE POWER CONVERTERS FOR GRID-FORMING	The suggested method has four working modes, the majority of which run quietly without interfering with the power system. We need be familiar with system control in order to estimate grid impedance. Structure and setup of the grid-forming power converter and Kalman filter scheme approach for impedance estimation. The voltage or power control case can be used to operate grid-forming power converters.	1.Easy Implementation. 2.Accuracy of impedance detection is unaffected by control parameters for stable grid-forming converters. 3.Accuracy is strongly desired.	1.Disrupting Noise

4.	GRID-CONNECTED POWER CONVERTERS	An on-grid inverter converts continuously fluctuating solar power DC and feeds it into the mains power supply. It synchronizes the voltage and frequency of its output.Two IGBTs are used as rotor side and grid side converters in power electronics. BJT is not used as converter. The currently prevailing control methods implemented in DC-DC converters are voltage-made, current-mode and hysteretic control.	1.Long life Small size High-quality power to the grid Flexibility in operation 2. Low thermal dissipation	1.Complicated design, 2. Harmonics, 3. Low power factor 4.Low Overload capacity.
5.	H-INFINITY CONTROLLER FOR BUCK-BOOST CONVERTER	There are different operational modes in converter's operation for steady states modelling the DC_DC Converters. Voltage mode controller is used for improve the control performance of Buck _Boost converter. The output voltage of the converter is determined by the duty cycle magnitude..	1.Simplicity No additional components required 2. Fast Transient response	1.Slow response to load variations 2. Slow Transient response
6.	PROGRAMMABLE CONTROLLER IC FOR DC-DC CONVERTER	In order to accomplish a unity power factor correction, the input voltage and current waveforms are first controlled using a hybrid control technique. In this technique we used SAR-A/D Converter, Digital PID, PWM using Programmable Counter Array and we use DC-DC boost converters for simulation purpose.	1.Simple structure, 2. High Band-width Low cost.	1.Lack of security, 2. Large power requirement

7.	SISO Modeling for Grid-Connected Voltage-Source Converter Stability Analysis	we use SISO Nyquist stability test method to be applied for stability analysis and controller design, provided that certain assumptions are true. The resulting model is validated using time-domain simulations and experiments.	1.No commutation failure 2.Reduced current harmonics 3.Independent control of active and reactive power.	Low bandwidth.

8.	Controller Design and Analysis for Fifth-order Boost Converter	To ensure load voltage management in the presence of uncertainties, the robust voltage-mode controller is constructed utilizing a contoured robust bode plot methodology. A step-by-step technique for designing a robust controller is provided.	1.Single-switch topology. 2. common ground between source and load 3. low voltage stress across intermediate capacitors.	The efficiency of the converter is limited by the active power switches, diodes, capacitors**.**
9.	A Grid-Connected Voltage-Source Converter Universal Controller	Grid-forming and grid-following methods, are referred to as Power-synchronization Control and Vector Current Control, with the latter containing cascaded outer loops. When connected to a poor grid, even one grid-following converter may experience stability issues. Grid-forming and grid-following controls do not, however, exist in completely separate domains, most grid-forming schemes have elements for grid-following.	1.Permitting stable well-performing operation irrespective of the grid strength	1.High hardware cost reduced transmission efficiency.
10.	Wind Turbine System Converter Controller Design Methods in the DC Micro Grid.	The authors suggest methods for constructing converter controllers for four types of wind turbine systems: variable speed induction generation systems, fixed speed induction generation systems, variable speed synchronized generation systems, and fixed speed generation systems.	1. Increased active power capacity. 2. Transmission losses can be minimized.	1.The switching frequency will be random.

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Conclusion:

This paper examined the challenges and control mechanisms utilized in renewable energy systems. Much of the issue derives from the intermittent nature of energy generation, which can be addressed in part by applying control techniques or integrating more than one generation method into the power system. In addition to the aforementioned devices, other equipment, such as batteries or diesel engines, can be added to the system to increase its robustness in the face of fluctuating energy generation. The control approaches discussed in this article give the necessary methodology for conducting the prescribed processes, and the results validate the technique. Power grids with substantial renewable energy generation confront stability concerns, which are not limited to power generation sources but can also apply to other devices with a power electronic converter interface at the grid connection end. Due to voltage and frequency changes and harmonics induced by the weak grid, autonomous power generation poses a substantial challenge in terms of power quality in connected systems. The paper addressed basic controls in renewable energy generation systems based on extensive literature research for wind, photovoltaic, and grid-connected systems, as well as stability issues. Furthermore, options for reducing instability were considered in this work.

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