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A Review Paper on Active and Reactive Power Control during Unbalanced Grid Voltage in Pv Systems

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Abstract:

Single-stage grid-connected PV systems provide many advantages such as simple topology, high efficiency, high power density, and lower cost. The active power reference is obtained from a Maximum Power Point Tracking (MPPT) algorithm. However, achieving MPPT, while conditioning the output power and synchronizing with the power grid, is a big challenge in such systems. The inverter is an essential element in a photovoltaic system. This review-paper focuses on different technologies for connecting photovoltaic (PV) modules to a three-phase-grid. Several grid-fault control schemes are nowadays available for operating under unbalanced grid voltage. Several grid-fault control schemes are nowadays available for operating under unbalanced grid voltage. These control schemes usually have extreme power quality characteristics. Some of them have been conceived to completely avoid power ripple during unbalanced voltage sags, but at an expense of high current harmonic distortion. With other schemes, the harmonic distortion is totally eliminated but at an expense of high ripple in the injected power. The aim of this paper is to highlight the important theory that are employed in simulation, while at the same time making awareness of some of the interesting challenges that remain to be solved.

Keywords

Control system, Photovoltaic systems, Low voltage ride through, Distribution system, PSCAD

1. INTRODUCTION

Photovoltaic, also called solar cells, are electronic devices that convert sunlight directly into electricity. Photovoltaic power were first discovered by a French scientist Edmond Becquerel in 1839. The first working solar cell was successfully made by Charles fritts in 1882. It was made of thin sheets of selenium and coated with gold. The use of solar panels for generating electricity and heat seems relatively like new development, it has actually been widely used to generate power since early 1900s [1]. In 2018 it is estimated a worldwide PV installed power of about 321 GW [2]. Grid-connected Photovoltaic systems usually employs two stages: The first stage is a dc-dc boost converter for boosting the PV voltage, and achieving MPPT; and the second stage is a dc-ac inverter for conditioning the output power and synchronizing with the power grid. However, such systems have drawbacks as higher part count, lower efficiency, lower reliability, higher cost, and larger size [3]–[4]. On the other hand, single-stage grid-connected systems provide many advantages such as simple topology, high efficiency, high power density, and lower cost. However, achieving MPPT, while conditioning the output power and Synchronizing with the power grid is a big challenge in such systems [4]–[5]. In Fig.1 also the components of a photovoltaic system are shown which explains the importance of each connected components with the whole system.

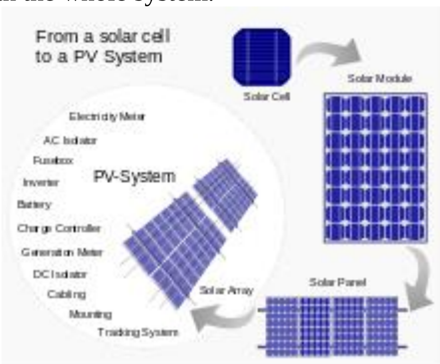

Fig 1: Diagram of the possible components of a photovoltaic system

2. PHOTOVOLTAIC SYSTEM

Grid-interconnected Photovoltaic (PV) source is one of the fastest developing and most prominent renewable energy sources in the globe. The main reason behind this is the remarkable progress in the semiconductor manufacturing domain. Also, the reduction in price of PV modules helps in the starting of economic incentives or subsidies. Although, the core of a PV system is the PV cell (or PV generator), power electronics sector plays a major role as a cutting edge technology for an efficient photo voltaic system control, hence transferring the generated power to the grid supply. The functions of the power converter of a PV system consists of Maximum Power Point Tracking (MPPT), DC/AC power converter, grid synchronization, power quality, active and reactive power control – and anti-islanding detection power converter interface of grid-connected PV system. The system has a PV generation set-up, which can be a single module, a

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string of series-connected modules, or an array of parallely connected strings. PV inverters nowadays have high demand, which are manufactured in different topologies. The configuration of series/parallel connections of PV modules with 3-Ø central string inverter is common for PV plants (10 to 250 kW & more) that gives high efficiency.

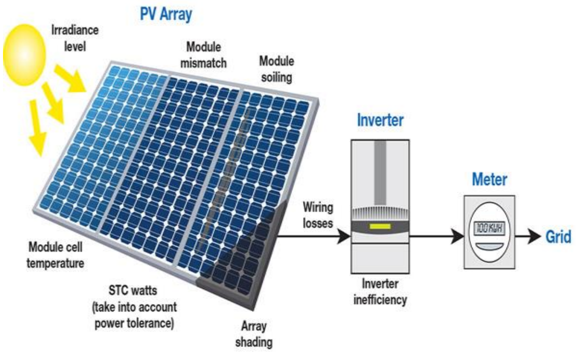

Fig. 2: Arrangement of PV Array

In Fig 2 the arrangement of PV Array along with the setup is shown. It includes the PV array with the inverter connected to the grid.The PV set-up has a passive input capacitive filter, which decouples the input voltage and current from the subsequent power stages by reducing current and voltage ripples at the PV cell side. The input capacitive filter circuit after filtering the ripples comes to DC/DC boost converter, where MPPT techniques of PV system are performed. Moreover, galvanic isolation are also introduced (when DC/DC converters with High Frequency (HF) transformers are employed). The DC/DC chopper block is connected through a DC link to a grid-tied DC/AC central inverter, commonly known as PV inverter. In PV systems – where no DC/DC converter is used, the input filter is equivalent to the DC-link capacitor. The PV inverter is connected to grid source through output filter, usually a combination of inductors (L) and capacitors (C). The AC side filter enables harmonic mitigation – and helps the converter–grid interface control. Depending on the PV system requirements and the grid connection, a Low Frequency (LF) transformer is used to increase the voltage and give isolation to the circuit.

. A large PV plant with centralized configuration is shown in Fig. 1. The PV array is connected to the grid by a power converter which carries out MPPT as well as controls of the active and reactive power flow. Most PV systems operate below a thousand volts hence a transformer is used to increase the Low voltage (LV) generated to a Medium Voltage (MV); typically in star-delta connection (Y-Δ).The power from the PV plant is transmitted to a substation where a transformer elevates the voltages from medium to high voltage power transmission.

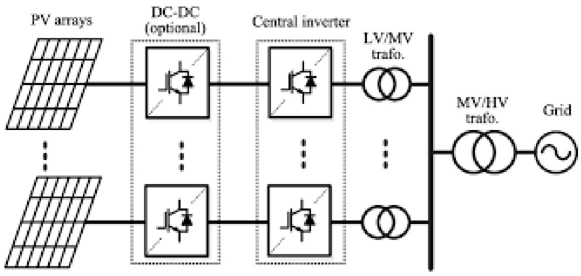

Fig.3:. Typical scale PV plant connected to the grid.

3. GRID CONNECTED SYSTEMS

In grid-connected applications, the power is supplied directly to the grid – and the important blocks are photo voltaic modules and inverters. This decreases the overall price of the plant and also reduces the necessary maintenance required, as the batteries are the most maintenance-demanding parts.

- These installations are based on housing applications, where power requirement is (<5kW). Also, larger PV power plants are rapidly going in construction to achieve a nominal power level up to 250 MW.
- Currently, the main installed PV set-ups are grid-connected with the off-grid sector accounting for an estimated 2% of global capacity. The output of PV panels is a DC voltage, and photo voltaic central string inverter gives an AC output voltage.
- PV set-ups, where each photo voltaic panel has its own module inverter, are commonly used for low-power applications – where power levels are below 500 W.

The PV inverters for grid connection can be of different topology and operation than off-grid ones. They have to produce excellent quality sine wave outputs with low ripples i.e., less THD, which has to match the frequency and voltage of the grid for synchronization and extract maximum power from the PV modules through the MPPT algorithm. The inverter input finds from I–V curve of the photo voltaic string cell until the maximum power point is achieved.

- The PV grid inverter always controls the grid & output voltage and frequency. The most effective modulation technique is the Pulse Width Modulation, which can function at frequency ranging from 2 to 20 KHz.
- Grid connected inverters are classified as Voltage Source Inverters (VSIs) and Current Source Inverters (CSIs). However, in PV applications, VSI inverters are used. The complete diagram of PV panels & VSI with grid integration is provided in Fig.4.
- With the present accelerated efforts on the part of manufacturers, designers & utilities with adequate

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government support, PV systems will occupy a place in country's power sector in the next few decades. Grid-connected solar PV systems can provide some relief towards future energy demands.

- Solar PV is the technology that offers a solution to a number of issues associated with fossil fuels. It is clean decentralized, indigenous and environmentally friendly. On top of that, India has among the highest solar irradiance in the globe which makes Solar PV more attractive for India.

In Fig 4 the variables required to control the system are shown. The PV module array is connected to a single stage inverter which must ensure the injection of active power.

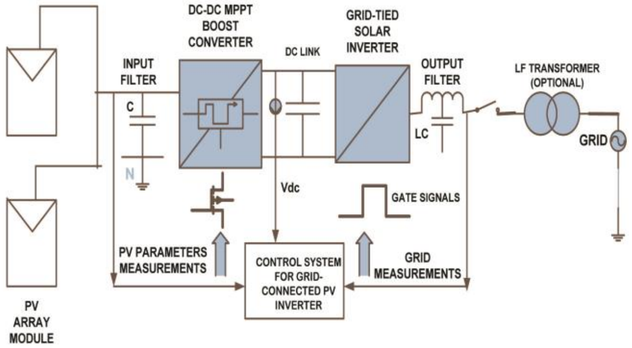

Fig. 4: Generalized Block Diagram of Grid-Connected PV System.

4. MPPT METHOD

Maximum power point tracking (MPPT) [6]-[7] is a technique used commonly with photovoltaic (PV) solar systems to maximize power extraction under all condition.

PV solar systems exist in many different configurations with regard to their relationship to inverter systems, external grids, battery banks, or other electrical loads. Regardless of the ultimate destination of the solar power, though, the central problem addressed by MPPT is that the efficiency of power transfer from the solar cell depends on both the amount of sunlight falling on the solar panels and the electrical characteristics of the load. As the amount of sunlight varies, the load characteristic that gives the highest power transfer efficiency changes, so that the efficiency of the system is optimized when the load characteristic changes to keep the power transfer at highest efficiency. This load characteristic is called the maximum power point and MPPT is the process of finding this point and keeping the load characteristic there. Electrical circuits can be designed to present arbitrary loads to the photovoltaic cells and then convert the voltage, current, or frequency to suit other devices or systems, and MPPT solves the problem of choosing the best load to be presented to the cells in order to get the most usable power out.

In this method the derivative of PV output power with respect to its output voltage is calculated (dP/dV). When dP/dV approaches zero the maximum PV output power can be achieved [11], [14]. The controller calculates dP/dV based on the measured PV incremental output power and voltage. If dP/dV is not close to zero, the controller will adjust the PV voltage step by step until dP/dV approaches zero, at which the PV array reaches its maximum output.

Solar cells have a complex relationship between temperature and total resistance that produces a non-linear output efficiency which can be analyzed based on the I-V curve[8]-[9]. It is the purpose of the MPPT system to sample the output of the PV cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions [10].MPPT devices are typically integrated into an electric power converter system that provides voltage or current conversion, filtering, and regulation for driving various loads, including power grids, batteries, or motors.

- Solar inverters convert the DC power to AC power and may incorporate MPPT: such inverters sample the output power (I-V curve) from the solar modules and apply the proper resistance (load) so as to obtain maximum power.
- The power at the MPP (Pmpp) is the product of the MPP voltage (Vmpp) and MPP current (Impp).

4.1 MPPT IMPLEMENTATION

When a load is directly connected to the solar panel, the operating point of the panel will rarely be at peak power. The impedance seen by the panel derives the operating point of the solar panel. Thus by varying the impedance seen by the panel, the operating point can be moved towards peak power point. Since panels are DC devices, DC-DC converters must be utilized to transform the impedance of one circuit (source) to the other circuit (load). Changing the duty ratio of the DC-DC converter results in an impedance change as seen by the panel. At a particular impedance (or duty ratio) the operating point will be at the peak power transfer point. The I-V curve of the panel can vary considerably with variation in atmospheric conditions such as radiance and temperature. Therefore, it is not feasible to fix the duty ratio with such dynamically changing operating conditions. MPPT implementations utilize algorithms that frequently sample panel voltages and currents, then adjust the duty ratio as needed. Microcontrollers are employed to implement the algorithms. Modern implementations often utilize larger computers for analytics and load forecasting.

5. DC-DC CONVERTER

The DC-DC converters are widely used in photovoltaic generating systems as an interface between PV module and the load. These converters must be chosen to be able to match the maximum power point (MPP) of PV module when climatic conditions change with different resistive load values. So DC-DC converters must be used with MPPT controller in order to reduce losses in the global PV system' When climatic conditions change, the boundary of inductance and capacitance parameters of DC-DC converter will change. In order to limit the output voltage ripple of DC-DC converter below a desired value, the filter capacitance must be larger than the maximum value of boundary capacitance [11],[13].

The mathematical analysis of this method is explained using;

$P = V\,I$ (1)

When there is small change in current and voltage, the power is modified and given by [11], [15];

$P+\Delta P = (I+\Delta I).\,(V+\Delta V)$ (2)

After ignoring small terms, equation (2) is simplified to;

$\Delta P = \Delta V.I + \Delta I.V$ (3)

ΔP must be zero at peak point. Therefore, at peak point we can write equation (3) as

$dI/dV = -\,I/V$ (4)

The incremental algorithm is based on the following equation holds at the MPP [14]:

$dI/dV + (I/V) = 0$ (5)

6. RELATED WORK

S. Jain and V. Agarwal proposes [4] a high performance, single-stage inverter topology for grid connected PV systems. The proposed configuration can not only boost the usually low photovoltaic (PV) array voltage, but can also convert the solar dc power into high quality ac power for feeding into the grid, while tracking the maximum power from the PV array. Total harmonic distortion of the current, fed into the grid, is restricted as per the IEEE-519 standard. The proposed topology has several desirable features such as better utilization of the PV array, higher efficiency, low cost and compact size. Further, due to the very nature of the proposed topology, the PV array appears as a floating source to the grid, thereby enhancing the overall safety of the system. A survey of the existing topologies, suitable for single-stage, grid connected PV applications, is carried out and a detailed comparison with the proposed topology is presented. A complete steady-state analysis, including the design procedure and expressions for peak device stresses, is included. Necessary condition on the modulation index "M" for sinusoidal pulsewidth modulated control of the proposed inverter topology has also been derived for discontinuous conduction mode operation.

F. Gonzalez-Espin proposes [5] the proportional + resonant (PR) controller in the past as a suitable method to control the current generated by the grid-connected photovoltaic voltage source inverters. The information regarding the frequency of the grid is needed to use this control technique, the synchronous reference frame phase-locked loop (SRF-PLL) is commonly used. To assure that the total harmonic distortion of the injected current (THDi) meets the appropriate standards, even if the grid voltage is polluted and its frequency varies, an adaptive control strategy is presented in this paper. This control strategy can improve the behavior of both, the conventional SRF-PLL and the conventional PR controller, when they are used in a polluted grid with a time varying frequency. The experimental results obtained by means of a digitally controlled 10-kVA inverter, show up that the THDi of the injected current is improved when the proposed adaptive control strategy replaces the conventional one.

Surawdhaniwar proposes [10] the need for renewable energy sources is on the rise because of the acute energy crisis in the world today. India plans to produce 20 Gigawatts of Solar power by the year 2020, whereas we have only realized less than half a Gigawatt of our potential as of March 2010. Solar energy is a vital untapped resource in a tropical country like ours. The main hindrance for the penetration and reach of solar PV systems is their low efficiency and high capital cost. To maximize a photovoltaic (PV) system's output power, continuously tracking the maximum power point (MPP) of the system is necessary. Maximum power point tracking (MPPT) is a technique that grid tie inverters, solar battery chargers and similar devices use to get the maximum possible power from one or more solar panels. Solar cells have a complex relationship between solar irradiation, temperature and total resistance that produces a non-linear output efficiency known as the I-V curve. It is the purpose of the MPPT system to sample the output of the cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions. Maximum power point tracking (MPPT) algorithms provide the theoretical means to achieve the MPP of solar panels; these algorithms can be realized in many different forms of hardware and software

.

S. Malki, [13] explains about the efficiency of the solar PV module which is low (about 13%).So it is desirable to operate the module at the peak power point in order to maximize the delivered power to the load under varying temperature and solar radiation conditions. Hence, maximization of power improves the utilization of the solar PV module. The dc-dc converter serves the purpose of transferring maximum power from the PV module to the load by changing the duty cycle. The load impedance as seen by the source is varied and matched at the point of the peak power with the source. So, the maximum power is transferred.

R. Faranda and S. Leva proposes [14] about the relationship between current and voltage of the PV cell which is non-linear. The entire PV system operates with maximum efficiency and gives its maximum output power. The location of the MPP can be determined, either through calculation models or by search algorithms in order to maintain the PV array's operating point at its MPP.

7. CONCLUSIONS

The goal of this study is to achieve the highest performance of DC-DC converters connected to a single PV module and controlled by MPPT throughout. The topologies of converters are commonly used in PV systems. This goal can be achieved only if each converter is properly sized. Also scheme is presented to control the active power supplied for a photovoltaic power plant to a power supply system under grid faults conditions. The strategy is to inject maximum power from the photovoltaic plant. So the proposed system is tested under different test cases which explains the LVRT capability in distribution power systems with a proposed DC-link voltage control system.

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