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INVERTER PERFORMANCE IN GRID-CONNECTED PHOTOVOLTAIC SYSTEM

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Abstract – Inverter, as one of photovoltaic (PV) system's component coordinates various operating states such as supplying power to the grid, purchasing electricity from the grid and self-supply with solar power. Since we notice that PV power supply is a one-way process, where current only flows from PV generator in one direction directly into the grid and gradually coming to an end. In its place, self-supply with solar power is gaining important. In medium voltage range, particularly inverters are also increasingly undertaking tasks to stabilize the grid during voltage fluctuations.This paper reviews the inverter performance in a PV system that is integrated with a power distribution network (i.e., medium to low voltage), or we called it grid-connected PV system. Since the PV system is connected to the public grid, then the inverter eventually called "grid-tie inverter" (GTI). In general, the inverter used is a centralized inverter with settings based on the multiple power point tracker (MPPT) algorithm. The MPPT control is installed on both DC and AC sides which requires a voltage setting that is in accordance with the PV system.

Keywords: Photovoltaic, inverter, power distribution network, MPPT

I. INTRODUCTION

Photovoltaic (PV) system interaction with the public grid is an ever more important factor in the efficiency and use of PV plants. Since the days of PV power supply as a one-way process, where current only flows from the PV generator in one direction (i.e. directly into the grid), are increasingly coming to an end. Instead, self-supply with solar power is gaining in importance.

Inverter, as one of PV system's component, has a function to coordinate various operating states, namely: supplying power to the grid, purchasing electricity from the grid and self-supply with solar power. In the medium voltage range, in particular, inverters are also increasingly undertaking tasks to stabilize the grid during voltage fluctuations.

This paper examines the performance of an inverter in a PV system that is integrated with the electricity distribution network. In the methodology section, the components of a PV system are discussed, including the inverter. In the Results and Discussion section, a centralized inverter that is generally used in PV systems is discussed using the MPPT algorithm setting which can adjust the appropriate voltage on the DC side. In the conclusion, it is concluded that the inverter performance has been discussed in the previous section.

II. SYSTEM ILLUSTRATION

A photovoltaic plant (PV plant) which feeds into the grid essentially consists of the following components:PV generator (solar modules), Generator junction box (GJB), Inverter, Meters, DC and AC cabling/connector, and Grid integration.

System variations result from the utilize of different modules (crystalline silicon or thin-film) and the way in which they are associated (e.g. in series), as well as the utilize of different inverters (with or without a transformer). Novel specialized improvements, such as smaller-scale inverters or DC optimizers, extend the range of potential system configurations.

Crucial differences in PV system innovation result from partitioning a PV generator into strings and interfacing these to one or more inverters. Partitioning the system into strings gives organizers more adaptability and empowers variables such as partial shading of the PV generator to be considered.

Inverters are chosen according to the type and amount of the modules connected as well as the voltage and output of the individual strings. A hierarchy may also be set up between inverters. In a large-scale PV plant, for example, partial load operation can be way better misused by coupling a few central inverters in a master/slave configuration. Here, the master inverter impairs or empowers the other inverters depending on the insolation, which changes during the course of the day.

Fig. 1 illustrates the common grid-connected PV system. The integrated components namely PV generator (solar module), solar module junction box, solar cable connector, generator junction box (GJB), inverter, meters, grid supply, monitoring solution, and power optimizer. The mentioned components are discussed briefly in this section.

A. PV Generator

The PV impact in solar cells can be utilized to generate power. Solar cells are made from a variety of

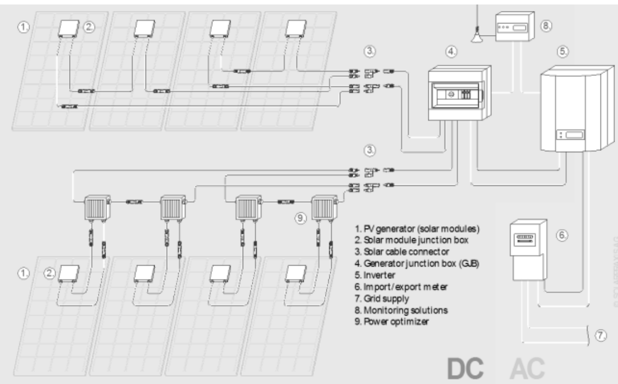

Fig. 1 Components of PV System[1]

different materials, with crystalline silicon being the foremost common. Thin-film cells made from cadmium telluride (CdTe), copper indium selenide (CIS), amorphous silicon (a-Si), and amorphous/ microcrystalline silicon (a-Si/_c-Si) are, in any case, moreover broadly utilized. Several solar cells are connected together to form a module.

The manufacture of PV cells is based on two different types of material: i) a semiconductor material that absorbs light and converts it into electron–hole pairs, and ii) a semiconductor material with junctions that separate photo- generated carriers into electrons and electron holes. The contacts on the front and back of the cells allow the current to the external circuit. Crystalline silicon cells (c-Si) are commonly used for absorbing light energy in most semiconductors used in solar cells[4].

The electrical properties of crystalline modules are uniquely different from those of thin-film modules and must be considered in order to attain the most elevated conceivable yield in a given area. Cells made from different materials have different efficiencies. PV array surface area depends on the type of cell utilized. Table 1 recorded the PV cell materials counting their efficiencies and output power.

Table I
PV Cell Materials[5]

Cell material	Module efficiency	Surface area need for 1 kWp
Monocrystalline silicon	13–19%	5–8 m²
Polycrystalline silicon	11–15%	7–9 m²
Micromorphous tandem cell (a-Si/μc-Si)	8–10%	10–12 m²
Thin-film copper-indium-diselenide (CIS)	10–12%	8–10 m²
Thin-film cadmium telluride (CdTe)	9–11%	9–11 m²
Amorphous silicon (a-Si)	5–8%	13–20 m²

The I-V curve of a crystalline silicon solar cell is illustrated in the following figure (Fig. 2). The open circuit voltage (V_{OC}) is around 0.5 V. At the maximum power point (MPP) of the curve, the voltage is about 80% of the open circuit voltage (V_{OC}) and the current is about 95% of the short circuit current (I_{SC}).

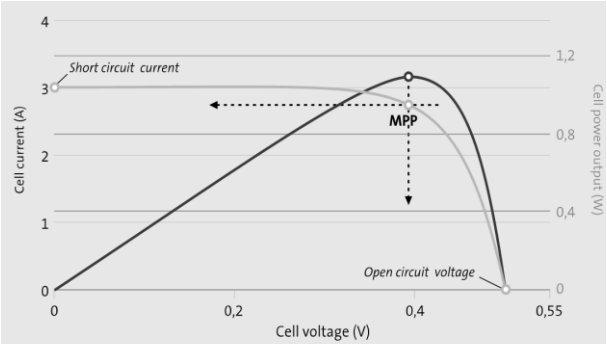

Fig. 2 I-V Curve of Crystalline Silicon Solar Cell[5]

B. Generator junction box (GJB)

Modules are connected in series to form a string, and the voltages of each individual module are totalled to provide the string voltage. Strings of equal length are then connected in parallel to form the PV generator, where the output power of the strings is aggregate. In case the PV generator comprises of more than three strings, the cables are solidified utilizing Y-adapters, or joined in a generator junction box (GJB).

The GJB is located close to the modules and connects the strings in parallel so that as it were one positive and one negative cable must be laid from each junction box to the downstream inverter. It can also perform extra safety-related functions, such as that of string fuse or overvoltage conductor. In case thin-film modules are utilized which are not reverse current proof, blocking diodes must too be utilized. In addition, there are certain components that may be situated in a few different locations within the system. For example, the main DC switch could be a part of the GJB or could be coordinated into the inverter.

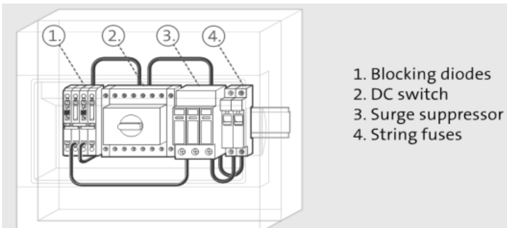

Fig. 3 GJB[1]

C. Inverter

The inverter is connected directly to the public grid, and must hence perform a few assignments at the same time. The foremost critical of these are multiple power point tracking (MPPT) tracking and converting the solar modules' DC into grid-compatible AC[6].

An inverter is a power converter that converts the DC provided by the PV generator into AC that has the same voltage and frequency as the grid. If required, this conversion might occur with an indicated phase shift, in order to feed reactive power into the grid (e.g. within the occasion of grid failure) and lend it back. Much obliged to state-of-the-art power electronics, converting direct current to alternating current presently only incurs minimal losses. The term "grid-tie inverter" (GTI) is additionally utilized for the device, since it is particularly adapted toward the prerequisites of the public grid[6].

Recent times have seen the development of ever-larger PV plants. As the modules utilized here are the same as those utilized in smaller installations, tens of thousands of them are required to construct megawatt-range solar power plants. The fact that PV generation involves so numerous small components means that, depending on the power rating, several alternatives are accessible for feeding into the grid.

Nowadays, inverters come in so numerous different sizes that, in principle, each module may be fitted with a customized inverter. Such module inverters basically empower ideal adjustment to the MPPT of each individual module. The AC output of these "micro-inverters" can be effortlessly connected in parallel, eliminating the need for DC cabling. In spite of the fact that it is simple to introduce on the rear side of the module, the devices have moderately low efficiency and high particular costs. To date, these small inverters are utilized in uncommon applications, such as installations with an output of between three and five kilowatts designed for utilization at the source small, such central inverters were the standard.

The technology of high-power inverters is reaching into the 2 MW class. Solar panels are being designed at 600 V bus voltage. Reference [7] provides an example, in Italy, the Rende installation used one MW inverter and produces 1.4 GWh per year. This design used 180W panels. By another decade, the installation can envision a scalable design of a rooftop solar PV system that can produce 2MW.

Nowadays, especially in large-scale PV plants, a variation of the central inverter with three to four inverters in hierarchical order (master and slave) is utilized. Whereas insolation is low, as it were the master is active, but as soon as its up- per output limit is reached, as insolation increments, the primary slave is switched in. The characteristic curve of the master-slave unit is composed of the curves of the individual inverters and so shows higher efficiency within the lower output range than a central inverter. To guarantee that the workload is distributed equally among the individual inverters, master and slave are rotated in a fixed cycle, which can be that each morning the inverter with the least working hours begins as the master[1].

In addition to the module and central inverters, string inverters give a third alternative, empowering the MPPT of each string to be tracked individually. This arrangement is perfect where strings get different degrees of shading all through the day, causing the operating points of individual strings to move differently. Here, the electricity is fed into the grid by several, independent string inverters. A further variation of the string inverter is the multi string inverter, which combines a few MPPTs in one device.

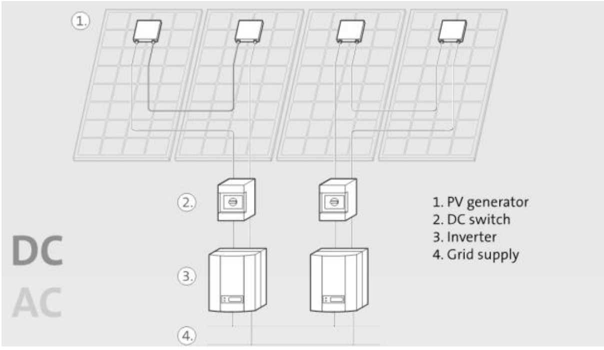

Fig. 4 Single String Inverter Module[1]

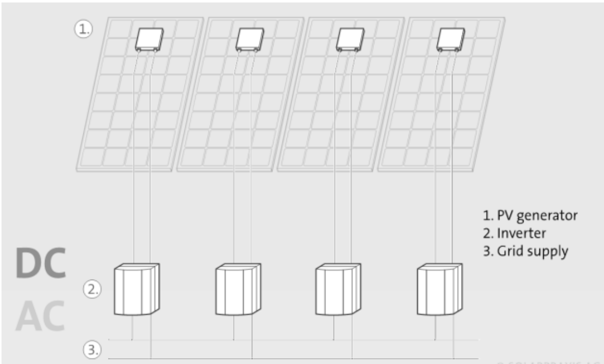

Fig. 5 Multi String Inverter Module[1]

D. Meters

In order to determine whether a PV plant is producing optimal output, the plant data has to be measured persistently, and ideally compared with the actual radiation values shown. Since currents and voltages, subsequently feed-in capacities, constantly adjust depending on meteorological conditions. The operator can only decide whether or not the PV plant's operational information indicates optimal functioning by specifically comparing them with insolation data.

Solar radiation is collected either by utilizing pyranometers or PV sensors. This aims to compare a plant's data with meteorological data and yields from PV plants in that locality. Additional measurement of the modules' operating temperature is vital to convert the insolation data to the target esteem by utilizing both PV sensors (Fig. 5), and pyranometers (Fig. 6). Since, with the same insolation, a module supplies a much more noteworthy yield on a cooler day than on a warm one[1].

Fig. 5 PV Sensor[1]

Fig. 6 Pyranometer[1]

E. Cables/connectors

The electrical connections in a system could be unnoticeable, yet their impacts should not be underestimated. As a moderately huge number of electrical connections are required in order to connect the modules of a PV plant to the inverter, the losses at contact points can add up. Long-lasting, secure cable connections with low contact resistances are essential to avoid defects, losses, and accidents.

Individual modules are connected using cables to form the PV generator. The module cables are connected to a string that leads into the generator junction box, and the main DC cable interfaces the GJB to the inverter. To eliminate the risk of ground issues and short circuits, the positive and negative cables, each with double insulation, need to be laid separately.

Solar cables (Fig. 7), which are UV and weather resistant and can be utilized inside a large temperature range, are laid outside. Single-core cables with a most extreme passable DC voltage of 1.8 kV and a temperature range from -40°C to +90°C are the standard here. A metal mesh encasing the cables improves protecting and overvoltage protection, and their insulation must not only be able to resist warm but too mechanical loads. As a result, plastics which have been cross-linked utilizing an electron beam are progressively utilized nowadays. Solar cables are single-cored, double-insulated and must withstand extraordinary weather conditions.

Fig. 7 Solar cable[1]

Fig. 8 PV connector[1]

Contacting can cause electric arcs. Secure connections are required thatconducts current fault-free for as long as two decades. The contacts must also appear permanently low contact resistance. Since numerous plug connectors are required in order to cable a PV plant, each single connection ought to cause as small loss as possible, so that losses do not accumulate. Given the valuable nature of the solar control obtained from the PV plant, as small energy as conceivable ought to be lost. Terminal screws and spring clamp connectors are continuously being replaced by uncommon, shock-proof plug connectors, which simplify connection between modules and with the string cables[1].

F. Grid integration

Guidelines and standards regulate precisely how PV plants ought to be connected to the public grid, which gives rise to two highly vital requirements. Firstly, when solar power is fed into the grid the power quality of the grid should not be reduced. Secondly, individual security must be guaranteed within the occasion of mains impedances. Another requirement has also recently picked up significance: PV plants should support the power grid and perform grid-related control functions[8].

The requirements for power in-feed are clearly characterized: The grid requires sinusoidal alternating current with steady voltage and frequency, and the harmonic component limits are directed in guidelines and standards. Modern inverters meet these power quality requirements, however in a few cases limits may be surpassed. Fig. 9 illustrates the common basic grid-connected PV system.

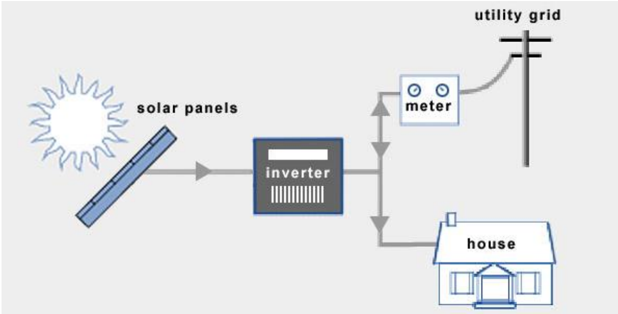

Fig. 9 Illustration of Grid-Connected PV System[2]

III. RESULT AND DISCUSSION

This section discusses the inverter model that is integrated with the PV system on the distribution network referring to the voltage control on the DC side.

A. Inverter technology for Grid-Connected plants

A PV generator produces DC electric and can subsequently only supply loads which work with this form of current, basically with voltages of 12, 24 and 48V, respectively. Usually loads work with AC and if the plant is connected to the power transmission grid the output current must be of this sort; European standards envisage 230V/50Hz for single-phase and 400V/50Hz for three-phase systems[9]. Hence, the need to transform DC output from the PV generator to AC. Typically done by the inverter, which apart from the DC/AC conversion moreover increases the output voltage up to the network voltage level for consideration within the network. The current presented must in reality have a sinusoidal waveform and be synchronized with the network frequency and, in case of power failure, indeed for brief periods, the inverter must be able of disconnecting instantly. Another essential highlight for inverters is the optimization of the effective energy production of the plant with respect to the incident solar radiation, by regulating the Maximum Power Point (MPP).

A single inverter handles the entire plant, which can supply power even within the MW range. All the strings, made up of modules connected in series, are joined together in a parallel connection. Points of interest of this solution are constrained financial speculations, plant simplification and reduced maintenance costs. One drawback is the sensitivity to partial shading in this way restricting the ideal exploitation of each string. It is perfect for solar fields with uniform orientation, inclination and conditions of shade[10].

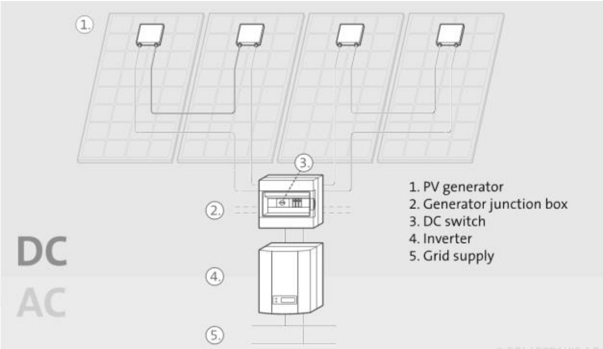

Fig. 10 PV Array Consists of Several Strings of Series-Connected Modules Served by a Single Central Inverter[1]

B. Control of Grid-Connected Inverter Systems

Reactive power control plays an important role in smart inverter functions. According to most references, Volt/Var control is more often to be utilized than current control. This can be occurred since in voltage-mode control the MPPT is less difficult due to the direct management of PV voltage on the DC side.

In voltage control, switch signals are generated by utilizing pulse width modulation (PWM) under the comparison result between reference sinewave signal and a fixed triangular waveform. Its modulation ratio is characterized as the ratio of reference signal peak amplitude and the sufficiency of triangular wave, which as it were influences the frequency spectrum of output voltage but has nothing to do with the RMS value of output voltage and current. Hence, there is ordinarily a DC/DC converter installed between PV and inverter in order to control the output voltage and current which consequently obtain the specified output power from PV. The DC/DC converter is also where the MPPT algorithm is applied.

A DC/DC converter is still required to maintain a proper voltage for the system, which implies its duty cycle and switching frequency unavoidably become additional factors to be controlled. Fig. 11 illustrates the MPPT control at DC and AC sides.

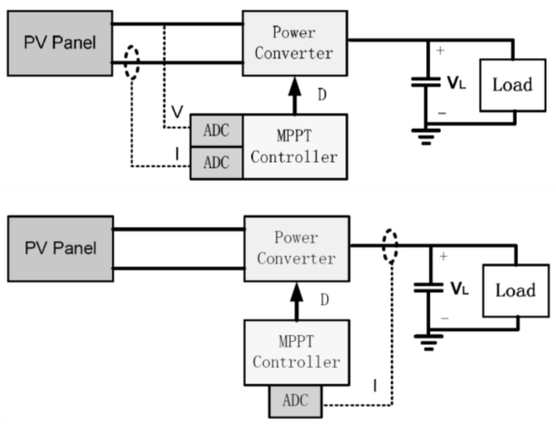

Fig. 11 MPPT Control on The DC Side and AC Side

Unpredictable shading effects caused by passing clouds are a common issue for photovoltaics, under which circumstance the voltage change will be within seconds. A controller with speedier response is required to handle the issue. OLTC, compensator reactive power control, DG reactive power control and DG active power control can also help mitigate the issue.

Voltage compensators, usually capacitors banks, are commonly implemented along long distance feeders to bring up voltages. In case of voltage rising as more PVs are installed, disconnecting these capacitors accordingly helps maintaining voltage level, but still they cannot be switched on and off too fast. Reactive power control on PVs could be a better solution, which is essentially done on inverters that connects PV and the grid. Fig. 12 illustrates the system which at its operation it has the compensating for the voltage rise effect.

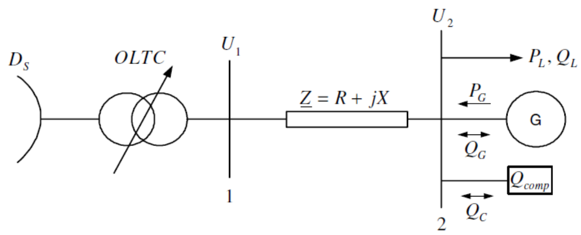

Fig. 12 A System Illustrating The Operations for Voltage Rise Effect Compensation

IV. CONCLUSION

This paper summarizes the inverter performance in a PV system that is integrated with a power distribution network. In general, the inverter used is a centralized inverter with settings based on the MPPT algorithm. The MPPT control is installed on the DC and AC side which requires a voltage setting that is in accordance with the PV system.

Voltage compensators, usually capacitors banks, are commonly executed along long separate feeders to bring up voltages. In case of voltage rising as more PVs are installed, disconnecting these capacitors appropriately helps maintaining voltage level.

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