Review of High PV Penetration issues and its mitigation with Constant Power Generation technique

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Abstract : The installed capacity of photovoltaic (PV) systems in India reached 18.7 GW at the end of 2017 and is increasing day by day. High PV penetration rises many issues in the system. This paper gives brief review of these issues. One of the problem is instantaneous change of voltage. Mitigation technique using Constant Power Generation (CPG) control is proposed here with modified MPPT control of DC-DC converter to solve voltage change problem without using any expensive energy storage device. A two stage three phase PV system is simulated in MATLAB environment. Result shows that using CPG problem of instantaneous change of voltage is mitigated.

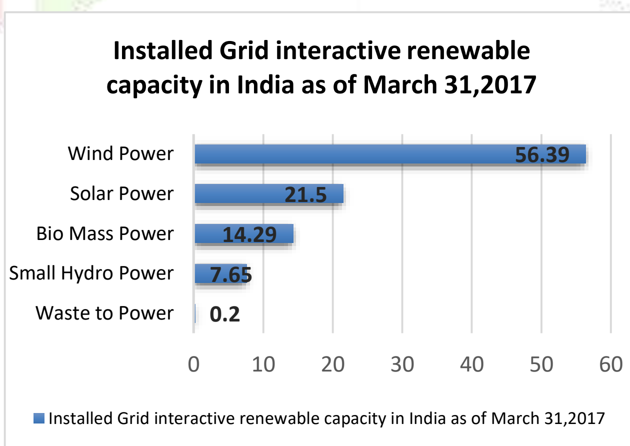
***IndexTerms* - Photovoltaic(PV), Distribution Genetation(DG), High PV penetration, Constant Power Generation(CPG).**

I. INTRODUCTION

The universal demand for electrical energy is on the rise due to continuous increasing demand by industrial as well as by domestic users. Increased energy consumption raises the serious environmental protection issues which leads us to use renewable energy as an alternative solution. Generation of electrical power at a small scale, ranging from 3kW to 10MW, by use of renewable energy is a concept of Distributed Generation (DG). It is normally installed in a distribution system close to the end user to provide power demand [1]. The most commonly used DG technologies are photovoltaic cells, small hydropower, wind power, fuel cells and biomass as these are inexhaustible and are renewed by nature itself. Hydropower plants are not useful when there is lack of water availability. Fuel cells have storage issues, high cost and highly flammable. Wind power requires high capital cost. It is very noisy, requires big acreages of land have to be used and harmful for birds by turbine. Biomass releases carbon dioxide (CO_2), a greenhouse gas. So, it has also a problem. So Photovoltaic system is widely used to generate electricity because it is pollution free, don't need any fossil fuels, has no moving part. It renewed by itself by sun and no harmful water or air pollution create.

Fig.1 shows that among all renewable energy sources, in India electricity generation is produced maximum by wind energy sources. Most reliable source of renewable source of energy is PV generation which is most promising renewable energy technologies and foreseen to replace the all conventional sources by 2040 [3]

Figure: 1 Installed Grid interactive renewable capacity in India as of March 31, 2017



In early 1980s India which has setup ministry of non-conventional energy resources among the world. As of September 2017 India's total renewable energy generation has reached 58.3 GW. Out of this 55.8% of the renewable power comes from the wind while 22.5% of renewable power comes from solar and as of September 2017, the country's solar grid had a cumulative capacity of 13.1 GW compared to 6.76 GW at the end of August 2017. Total solar capacity is expected to touch 18.7 GW by the end of 2017, which is about 5 per cent of global solar capacity, and further increase to 8 per cent by 2035. At Cochin, Kerala India has setup 100% solar powered airport. [2] Moreover, installation level of single phase rooftop PVs is also increasing along with installation of PV system in distribution system.

In this paper, PV penetration is defined as the ratio of total peak PV power to peak load apparent power on the feeder.

$$\text{PV Penetration} = (\text{Peak PV Power}) / (\text{Peak Load Apparent Power})$$

There are many PV Penetration according to load. When PV generation are increased than demand of loads e.g. 10%, 30%, 50% etc., High level of PV penetration are increased.

With enough capacity of PV system in the distribution system PV generation may match the demand or may not match the load demand [4]. If PV system has generation capacity equal to connected load, the load will be supplied by PV system only. If PV system has generation capacity less than the connected load, the part of load will be supplied by grid also. And when the PV generation is more than connected load, excess generation will be given into the grid as shown in table – 1.

Table no. 1. CASES OF PV GENERATION AND LOAD DEMAND

Sr. No.	**Power Generation Vs Load Demand**	**Load Supply**
1	$P_{pv} = P_{load}$	By only PV generation
2	$P_{pv} < P_{load}$	By Both PV and Grid
3	$P_{pv} > P_{load}$	By PV generation and excess power feed into grid

This paper presents brief overview of different impacts of high PV penetration in distribution networks and various mitigation techniques to use to solve out these impacts.

It is shown here that if PV system is operated in Constant Power Generation (CPG) mode, then problems due to high penetration level of PV system can be resolved.

II. IMPACTS OF HIGH PV PENETRATION ISSUES ON DISTRIBUTION SYSTEM

PV system generation depends on the environmental and geographical condition of the area. Solar power output depends on the irradiation level and temperature. As the irradiation level and temperature varies instantaneously, there is instantaneous change in the voltage. The voltage imbalance is also caused by the roof top installed single phase PV panel. With high penetration of PV generation into the grid, the aging transmission and distribution line has to deal with increased amount of fluctuating power because. And as the frequency has direct relation with the active power generated, the frequency fluctuation is also there with change in PV power generation. Moreover, with high PV Penetration, when the PV generation is more than the load demand, the excess power is feed into the grid i.e. reverse power flow will take place [4].In this section, various problems of high PV penetration in the distribution network is addressed briefly.

a. Over voltage Problem:

In distribution networks, when generation is increased, in summer, at noon or at clear sky, PV penetration level is increased during these peak time. It is increased much higher than the peak demand. So, at that time grid or load gets more power than required power. It changes between grid voltages and PV voltages. So, Grid can't be operated with rating condition. The voltage range is 90% to 110% of nominal voltage value. [5].

The two most important issues that arise with that are:

- Over voltage, as the grid must be operated below 110% of nominal voltage.
- The thermal limit of cables and/or transformer is reached.

b. Instantaneous Change in Voltage:

Solar power output is directly proportional to the irradiation level and inversely proportional to temperature. So, as the solar irradiation level increases, the power output will increase and temperature level increases, the output power of PV will decrease [12]. So, as the irradiation level and temperature varies instantaneously, there is instantaneous change in the voltage and voltage varies suddenly. There is a change in voltage between present voltage and previous voltage. So, it changes continuously [10]. As a reason of this, output power changes instantaneously. So load cannot take continuous power. Sometimes it has taken more power than its demand and sometimes less power. So load cannot work as its rated working condition, so constant voltage condition is required to maintain constant.

c. Voltage Imbalance/Voltage Unbalance:

Voltage unbalance is the ratio of negative sequence to positive sequence voltage components and is represented in percentage terms as the voltage unbalance factor[7]. Voltage unbalance is a crucial power quality issue & need to be addressed. The voltage level at generation & transmission level are in balanced state. However, the voltage at utility side may be unbalanced due to variation in system impedance and/or unequal loading condition. Voltage unbalance has adverse effect on distribution transformer as well as on induction motor appliances on the load side. The induction motor may be subjected to overheating and de-rating due to voltage unbalance. Voltage unbalance also depends on the location and rating of distributed PV. The voltage unbalance is generally low & within permissible limit at the beginning of a distribution feeder. However, its value may violate the standard limit at the end of the feeder [7]. Voltage unbalance is a function of unequal loading & the worst case is possible for heavy load with no PV penetration. VU can be improved with the possible combination of medium PV penetration & medium loading conditions. The VU problem is significant for cases like medium PV penetration & heavy loading as well as high PV penetration & medium loading conditions. The VU problems are counteract by traditional approaches like upgrading of network, (write full form of OLTC), and real power curtailment.

d. Reverse Power Flow

The reverse power flow occurs when the direction of power flow is changed from its conventional direction. Traditionally the power flows from the generating source to the utility and it is unidirectional. But the power flow changes its direction when DG's are implemented. All the protective device earlier designed for unidirectional power flow need to be readjusted in integration with bidirectional flow of power [9].

The PV penetration during day time is not constant & depends on the solar irradiation & temperature. At certain extent of the day, the PV power may exceeds the local load demand and thus may feed power back to the grid or sub-station, thus resulting in the reverse power flow [8].

The distribution voltage should remain in the permissible limits. With the increase in voltage on distribution network, the current magnitude increases but in the reverse direction. The transformer is forced to match the bandwidth of reduced set point and PV has to carry wider set of load so as to maintain the distribution voltage within permissible limits.

e. Frequency fluctuation:

The higher penetration of PV must be strictly synchronize with the grid voltage & frequency. However the PV output power is a function of irradiation & temperature [10]. This fluctuating power from PV may result in the quality of power as well as the stability of the network. If PV is installed at the weak grid, the fluctuation may have serious impact to the system.

When the solar irradiance and ambient temperature have been simulated, the output power of PV array can be calculated. After that, the inverter extracts the maximum power from PV based on the MPPT control principles. Simultaneously, it converts dc electricity to ac electricity.

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Till now, all the above mentioned issues were solved with different techniques. But CPG is one technique with help of which all the above mentioned issues can be solved by a single technique. The detailed discussion of CPG is given in section III.

III. CONSTANT POWER GENERATION TECHNIQUE

To cope with this high PV Penetration issues, the Distributed System Operator (DSO) has to expand transmission / distribution line. But it imposes extra cost on the system. Therefore, it is not economical option. Another alternative is to connect energy storage device - battery with the PV system to deal with the fluctuating PV generation. When the generated power is more than the required load demand the battery will be charged by the excess energy which is used to supply the load during low irradiation condition. However, it is not economical as its cost is high, so its increases the total installation cost of PV system and due to its limited life [17].

So, the distributed system operators have to reduce the PV installation. But it is also not viable option because if the PV installation is reduces, then at lower irradiation condition the PV generation cannot fully supply the load.

While due to low X/R ratio of low voltage grid, active power control shows more effective than controlling the reactive power. This active power control is also known as the CPG control [18].

CPG control is used to limit the maximum feed in power to the grid i.e. it curtails the excess power feed into the grid. This CPG control is accompanied by modifying the MPPT algorithm. The MPPT-CPG control is realized by regulating the duty cycle of DC-DC converter i.e. Boost converter. PV system operates in two mode based on the PV output power and set maximum feed in power limit P_{limit} – either in Maximum Power Point Tracking (MPPT) mode or Constant Power Generation (CPG) mode [19,20].

According to this Maximum Power Point Tracking with the Constant Power Generation Control, if the available PV output Power P_{PV} is less than the set P_{limit} (limit of Maximum Power feed into the grid), then PV system operate in the Maximum Power Point Tracking (MPPT) mode. If the available PV output Power P_{PV} is greater than the set P_{limit}, then PV system operate in Constant Power Generation (CPG) mode to limit the maximum feed in power to the grid to P_{limit} [20,21] that is shown in figure 2.

So, the PV output Power is given by

$$P_o = \begin{cases} P_{pv}(t), \ When\ P_{pv}(t) < P_{limit} \\ P_{limit}, \ When\ P_{pv}(t) \geq P_{limit} \end{cases} \tag{1}$$

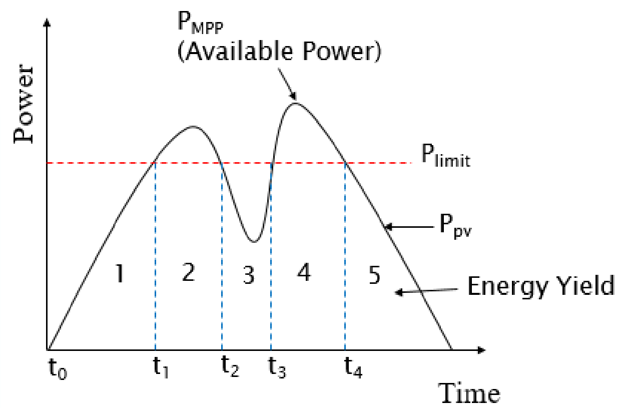

Figure 2. Power vs Time curve

IV. MITIGATION OF HIGH PV PENETRATION ISSUE WITH CONSTANT POWER GENERATION

In this section, operation of PV system in CPG mode is explained to solve problem related to instantaneous change in voltage due to high PV penetration.

Instantaneous change in voltage takes place due to change in irradiance and temperature. The solar constant is the average value of solar irradiance outside the earth's atmosphere, about 1366 W/m^2. Typically, peak value is 1000 W/m^2 on a terrestrial surface facing the sun on a clear day around solar noon at sea level, and used as a rating condition for PV modules and arrays. This same as for temperature is 25^{O}C [11,12].

So, when solar irradiance 1000 W/m^2 and temperature 25^{O}C are applied on the photovoltaic system, it will generate maximum power output. At that time irradiance and temperature are constant therefore PV will generate constant power and there is no change in irradiance and temperature.

But, in actual system solar irradiance and tempeature can't be constant. It varies with change in time and change in atmosphere because every time atmosphere is not possible with clear sky. So, output PV power will get many variation. So, connected loads will also take improper power and they won't work with desired condition. So at that time for continuous power supply constant power generation control is used.

V. SIMULATION DIAGRAM

Here two stage three phase PV system with varying irradiance and constant 25^{O}C temperature is used. Irradiance is changed from 1000 W/m^2 to 500 W/m^2 and 500 W/m^2 to 1000 W/m^2. This simulation work is carried out with MATLAB/Simulink 2016a. Figure 3 shows overall control structure of a two stage three phase grid connected PV system.

- *PV Panel:*

  The PV panel consists of series and parallel combination of solar cell which convert the solar energy into the electrical energy.

- *MPPT Algorithm:*

  Here, PV panel output voltage and current is taken as an input by P&O algorithm to generate the duty cycle for the boost converter to operate the PV system in MPPT mode. In this simulation perturb and observe technique is used to extract maximum power from PV panel.

- *Boost Converter:*

Boost converter is the main component of PV system used to operate the PV system in MPPT mode by varying its duty cycle D. It matches the input impedance of the PV system to the load impedance to transfer the maximum power.

The ratio of Output Voltage to Input Voltage is given as:

$$\frac{V_0}{V_{in}} = \frac{1}{1-D} \quad (2)$$

Where V_0 is the output voltage of the Boost Converter and V_{in} is the input voltage of the boost converter.

It also extends the operating time of the PV system at low irradiation condition by boosting the output voltage. So, for the same DC link voltage, the number of PV module required to be connected in series reduced.

- *Inverter and Inverter Control:*

The inverter is used to convert the DC power into AC power. The gate pulses for the inverter are generated by Sinusoidal Pulse Width Modulation (SPWM). In Sinusoidal Pulse Width Modulation, the Reference Signal compares with the Carrier Signal. When the Reference Signal magnitude becomes equal to or greater than the carrier signal amplitude, the gate pulse is generated.

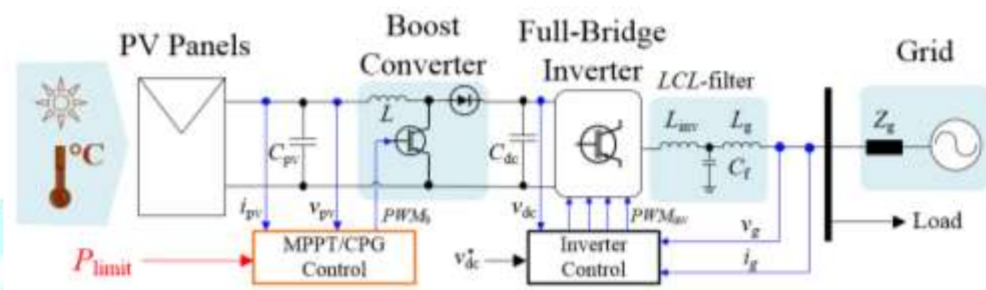

Figure 3. Overall control structure of a two-stage three phase grid-connected PV system

Table no. 2. PARAMETERS OF THE TWO-STAGE THREE-PHASE PV SYSTEM

PV module	3 kW
Boost converter inductor	L = 7 mH
PV side capacitor	C_{pv}= 5mF
DC-link capacitor	C_{dc}= 1.053 mF
Switching frequency	Boost converter: f_b= 20 kHz, Full-Bridge inverter: f_{inv} = 8 kHz
DC-link voltage	V_{dc}= 650 V
SPWM	Carrier wave frequency = 8 kHz Reference Signal Frequency: 50 HZ
Load voltage	400 V
Load frequency	50 Hz
Load active Power	P_L = 1500 W

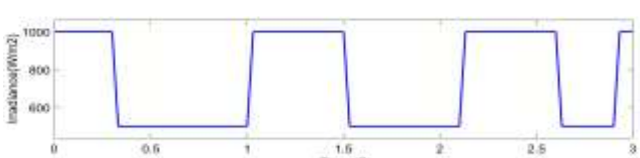

Figure 4. Irradiance (W/m^2) V/S Time (S)

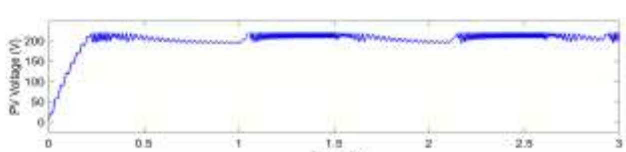

Figure 5. PV Output Voltage (V) V/S Time (S)

Figure 6. PV Output Current (A) V/S Time (S)

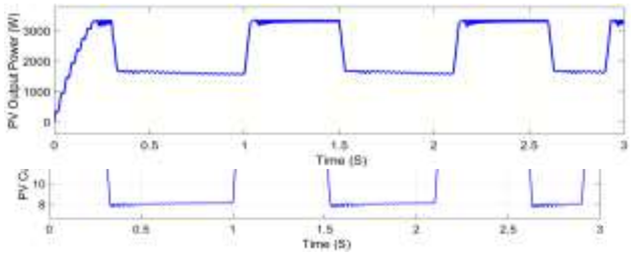

Figure 7. PV Output Power (W) V/S Time (S)

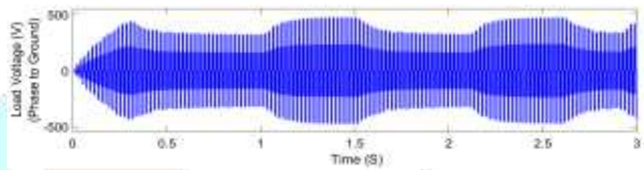

Figure 8. Load side voltage (p2g) (V) V/S Time (S)

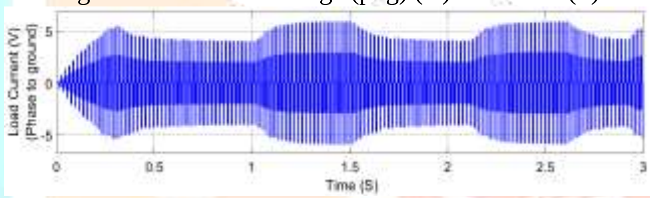

Figure 9. Load side current (p2g) (A) V/S Time (S)

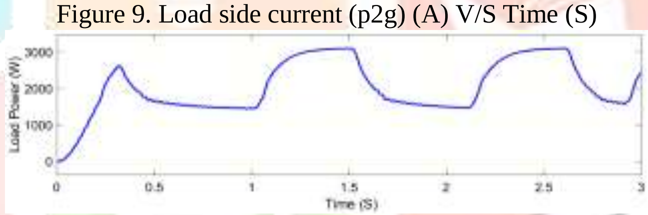

Figure 10. Load side Power (W) V/S Time (S)

Table no. 2 gives the parameters of two stage three phase 3.3 kW PV system. Load of 1.5 kW is connected with PV system. But when irradiance is varied 1000 to 500 W/m^2, PV output power also changes from 3.3 kW to 1.6 kW. At the same time load is not getting its rated voltage 400 V phase to phase and current 3.75 A as shown in figure 8 and figure 9. As the output voltage and current is changeing with the irradiance PV ouput power also changes.

CPG is one technique with help of which this issue can be solved. CPG control is used to limit the maximum feed in power to the grid i.e. it curtails the excess power feed into the grid and this control is accompanied by modifying the MPPT algorithm. PV system operates in two mode based on the PV output power and set maximum feed in power limit P_{limit} – either in Maximum Power Point Tracking (MPPT) mode or Constant Power Generation (CPG) mode.

When PV system generates more power than demand, with a set limit of power in CPG, power generation is controlled at a desired value [19]. If CPG along with MPPT is used in PV system, problems discussed in section – II can be solved out.

VI. Conclusion

This paper reviews different high PV pentration issues. CPG technique is proposed here to solve these issues. Using CPG, problem of instantaneous change of voltage in high PV peneration senario is solved out here. Here, CPG is accompanied by modifying MPPT alogrithm. CPG is the easy to implement and does not required any extra cost or extra grid or battery storage which shows superiarity of CPG over other techniques.

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