A Review on the MPPT Techniques and LVRT Requirements for Different Grid Codes Concerning PV System Integrated to Electric Power Network

Sahana M[1], Sowmyashree N[2]
[1]*PG Scholar, Department of Electrical and Electronics Engineering, JSS Science and Technology University, Mysuru, Karnataka, India.*
[2] *Assistant Professor, Department of Electrical and Electronics Engineering, SJCE, JSS Science and Technology University, Mysuru, Karnataka, India.*

***Abstract*—Low voltage ride through capabilities is one among many of the unexplored challenges in integrating photovoltaic (PV) systems into the power grid. This paper presents a comprehensive review for several control techniques to assure the LVRT capability of grid-feeding converters. Along with that, various methods of MPPT techniques used in PV system and LVRT requirements for Grid connected PV system is presented. LVRT is an essential attribute of PV inverters that allows them to remain connected with the grid during short-term disturbances in the grid voltage.**

***Index Terms*—Low voltage ride-through, photovoltaic system, fuzzy logic control, Grid-connected inverter, MPPT.**

I. INTRODUCTION

In recent years, the penetration of grid-connected photovoltaic (GCPV) systems based on distributed generation (DG) has increased dramatically. This is due to a number of benefits, including reduced power generation costs, zero CO2 emissions, improved grid reliability, and reduced grid capacity. On the other hand, sporadic power generation in the DG-PV system can jeopardize normal operation, leading to voltage fluctuations, increased energy, and loss of reactive power. In addition, these PV systems operate in a fixed voltage range, which contributes to grid stability. [14]. Solar systems have become the world's most trusted and cleanest source of renewable energy and are expected to grow rapidly in the future [1,2,5]. Photovoltaic panels are used to convert solar energy into electrical energy. The electrical energy generated by the PV module can be stored in the secondary battery of the storage battery or supplied directly to the alternating current (AC) grid. PV systems can only supply electrical energy to the grid via single-phase or three-phase inverter circuits. [3]. In general, PV inverters are built to deliver power with a power factor of 1, especially at full power. Nevertheless, PV inverters have a low power factor if the PV does not generate enough power due to fluctuations in the weather. In addition, the power factor value of an oversized inverter operating at 10-20% of the full-scale range is well below 0.9 and in some cases 0.5. Therefore, a suitable power factor controller is required to improve the voltage profile of the PV inverter [4].

One of the most common failures is low voltage failure. PV arrays should avoid high power losses and remain connected to the grid under these low voltage conditions. This feature is known as low voltage ride through. In the event of a grid failure, there are two major issues that PV systems need to address to meet LVRT requirements. (I) DC link overvoltage and AC side overcurrent. (II) Reactive power injection. This is an effective solution for voltage recovery and grid support. [1]. If you do not address these issues and cannot find a solution, your system efficiency will be impacted [5, 14].

This article discusses various forms of MPPT technology, PV-technical challenges for LVRT from different GCs, and more. Therefore, the content of the review below is divided into several sections related to the above issues.

II. CHALLENGES AND PROBLEMS FACED BY PV SYSTEM

As mentioned earlier, the LVRT control action begins when the grid voltage drops below the nominal value. Therefore, under LVRT conditions, a fast and reliable dip detection method is essential. This dip detection is usually achieved by a phase-locked loop (PLL) [23]. Synchronous reference frame-based PLLs (SRF-PLLs) are commonly used to measure the RMS value of the line voltage during normal operation and in fault equilibrium. The main drawback of SRF-PLLs is the inability to accurately detect line voltage drops in the event of an unbalanced line failure [14, 18, 19, 20]. This lack of capability is due to the presence of negative sequence components rich in high harmonics under unbalanced sag conditions. Some researchers have proposed improvements to traditional SRF-PLLs, primarily focusing on enhancing the noise reduction capabilities of traditional SRF-PLLs and thereby improving their filtering capabilities. [23].

Another important task to be looked after when LVRT is associated is the use of current control strategy, which helps in limiting the magnitude of the injected currents, mitigating the double grid frequency oscillations within the injected power, providing voltage support at the PCC and ensuring that the injected currents are of low total harmonic distortion (THD). And also, most importantly during LVRT under unbalanced fault is to design an efficient dc-link voltage control strategy to prevent inverter shutdown due to overcurrent and to ensure reliable operation of the inverter. This control strategy also prevents overvoltage in the dc-link capacitor during power imbalance occurring under unbalanced fault conditions [12].

III. GENERAL CONTOL STRUCTURES OF PV SYSYEMS

The basic structural block diagram of three-phase-grid connected inverter-based PV system is shown in Fig. 1 below.

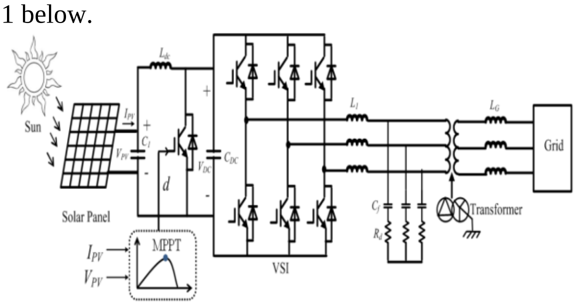

Fig.1 Block diagram of 3 phase grid integrated PV system

It consists of a PV array, the DC/DC boost converter with maximum power point tracker (MPPT) mounted on it for extracting optimum PV generated power, an intermediate DC link, a grid-side converter for DC to AC conversion, and the filter for mitigating harmonic injection as shown in Fig. 1 [6].

1. Solar PV cell

The model of solar cell can be categorized as p-n semiconductor junction; when exposed to light, the DC current is generated. As known by many researchers, the generated current depends on solar irradiance, temperature, and load current. The typical equivalent circuit of PV cell is shown in Fig. 2.

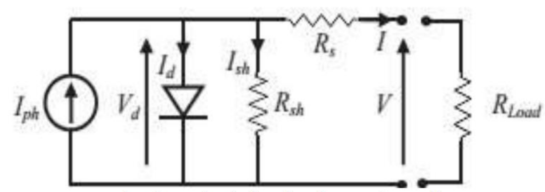

Fig. 2 Typical circuit of Solar PV cell

The net output current of PV

$I = I_{ph}Np – Id – I_{sh}$

Where,

I = Cell current(A)

NP = Number of solar cell connected in parallel

Iph= Photo current Id = The diode saturation current

Ish = Shunt Current

2. MPPT techniques

Maximum Power Point Tracking (MPPT) techniques are very significant, as one can improve the efficiency of the PV model through them. There are many methods of MPPT, such as the Perturbation and Observation (P&O), the incremental conductance, the Fractional Open-Circuit Voltage, the Fractional Short-Circuit Current, the fuzzy logic control and the Ripple Correlation Control. All the above vary in complexity, cost, popularity, convergence speed, hardware requirements and efficiency levels [7]. In this section, we examine Perturbation and Observation (P&O), incremental conductance and fuzzy logic control.

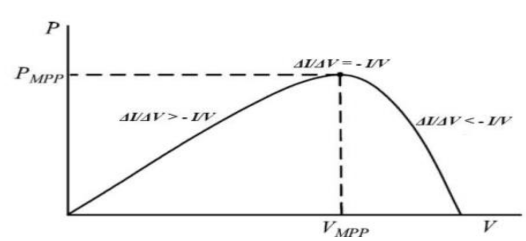

Fig. 3 IV characteristics of PV array.

A. Perturbation and Observation

Perturbation and Observation algorithm, also known as the hill climbing method, is one of the most commonly used (1) methods due to its ease of implementation. As can be seen in Fig. 5, the slope of the curve is zero at the maximum power point (MPP), positive on the left side of the MPP (increasing power region) and negative on the right side of the MPP (decreasing power region). Therefore, the algorithm is repeated and oscillated until the MPP is reached. The oscillation can be minimized by reducing the step-size of the perturbation, but this slows down the process reaching the MPP [10]. In Fig. 4 there is a flowchart of our implementation based on the P&O algorithm.

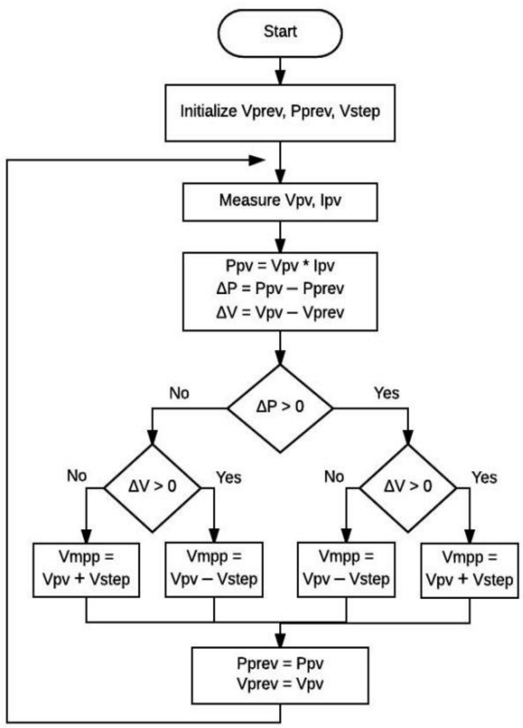

Fig. 4 Flow chart of Perturbation and Observe algorithm.

B. Incremental conductance

This technique is also considered as a hill climbing method. The MPP can be tracked by comparing the instantaneous conductance I/V to the incremental conductance ΔI/ΔV. In other words, the solution of equation (1) is zero at the MPP, positive on the left side of the MPP and negative on the right side of the MPP (Fig. 3).

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V\frac{dI}{dV} \cong I + V\frac{\Delta I}{\Delta V} \qquad (1)$$

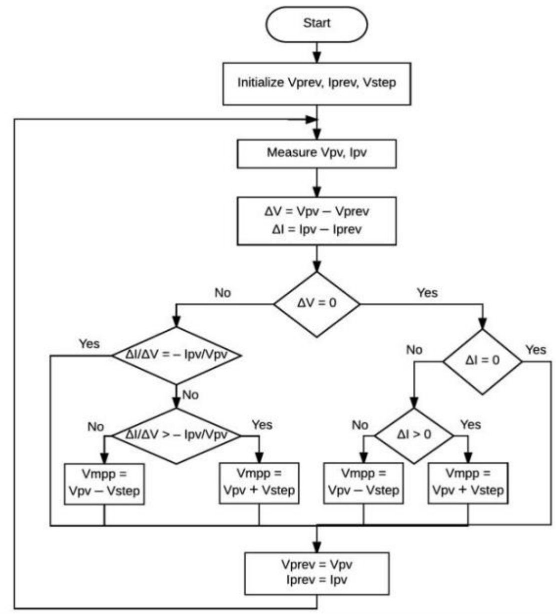

Fig. 5 Flow chart of incremental cunductance method.

The flowchart of our implemented algorithm is shown in Fig. 5. The incremental conductance algorithm is as efficient and simple as the P&O algorithm. Additionally, a variable step-size can be used to improve the response time, accuracy and performance of the system, but the cost may be higher due to the increased complexity of the control system [13].

C. Fuzzy Logic

Fuzzy logic is one of the most sufficient control techniques for MPPT, which has attracted many researchers in the last years. Fuzzy Logic controllers do not need an accurate mathematical model and can work with imprecise inputs. They have also the ability to handle nonlinear systems and control unstable systems [14].

The basic structure of any fuzzy logic controller is shown in Fig. 6 and consists of the following stages: fuzzification, rule base and inference engine, and defuzzification. Our proposed model takes as inputs the change in the array voltage (ΔVpv) and the change in the array power (ΔPpv) of the photovoltaic array. The output of the controller is the variation of the array voltage (ΔVref). It must be noted that different fuzzy input and output variables can be used [15]. For example, P-V slope and variation of P-V slope are some of the most common inputs, while converter duty cycle is used more often for output variable [16].

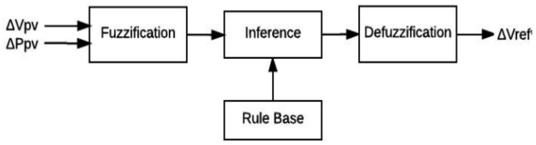

Fig. 6 Fuzzy logic control diagram

In the fuzzification stage, numerical input variables are converted into linguistic variables, such as NB (Negative Big), NS (Negative Small), ZE (Zero), PS (Positive Small) and PB (Positive Big) using basic fuzzy subset [17]. Each of them is described by a triangular-shaped membership function (Fig. 10). An alternative case may be also a Gaussian-shaped membership function [18]–[19]

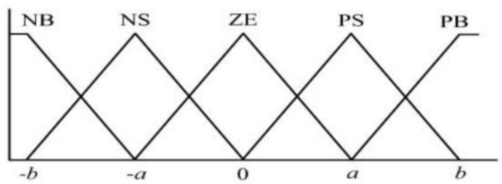

Fig. 7 Membership function for inputs and output of fuzzy logic controller.

The fuzzy inference engine processes the inputs according to the rules base table (Table I) and produces the linguistic output. The defuzzification stage is used to convert the output linguistic variable back to numerical variable. The centroid method, which is the most prevalent one, is used for defuzzification. The resulting output ΔVref is then added to the previous value of voltage to get the new value of the array voltage. This value of voltage is going back as input to the PV array.

Table 1. fuzzy logic rules base table

ΔV_{pv} \ ΔP_{pv}	NB	NS	ZE	PS	PB
NB	PS	PS	ZE	NS	NS
NS	PB	PS	ZE	NS	NB
ZE	NB	NS	ZE	PS	PB
PS	NB	NS	ZE	PS	PB
PB	NS	NS	ZE	PS	PS

IV. COMPARISON OF DIFFERENT GRID CODES CONCERNING LVRT CAPABILITY

In this section, FRT characteristic should be analysed and compared for different GCs at different countries and the differences should be explained regarding the varying power system topologies. Furthermore, short term voltage control requirements by reactive current injection during fault and restoring active power will be investigated within the relevant GCs.

The GCs states that the PVPP should withstand grid voltage dip (sag) to certain percentage of the nominal voltage as in some cases down to zero for specific duration. In this duration, PV units should operate normally without any disconnection. After faults' clearance, PV system must restore both active and reactive power fast enough to pre-fault value. Some codes stipulate that PVPP should feed the grid with reactive current to support the system voltage like traditional synchronous generators. This is called LVRT [1].

The international GCs comprise of LVRT curves are relatively similar to Figure-8 however, their characteristic may vary from one system to another. Figure-8 displays that Italian GC that requires PVPP to withstand faults and still connected to the system within 200ms when the voltage at connection point of PV system drop down to zero. If the voltage at connection point recovered to 85% of the rated voltage within 1.5 s after fault occurrence, PV units shall remain under continuous operation without tripping off.

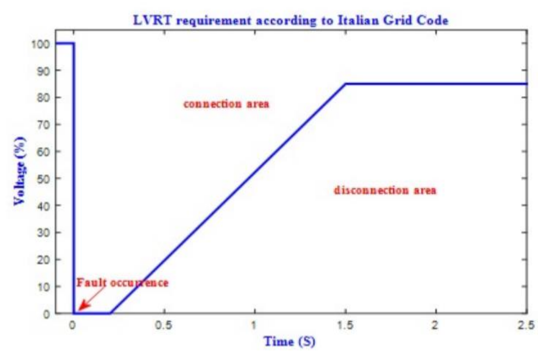

Fig. 8 The Italian LVRT requirement.

The German GC stipulated ride-through the fault when the voltage drop to zero for the maximum duration of 150 ms, followed by the voltage recovery to 90% of the rated voltage at PCC in 1.5s as shown in Table 2. The LVRT requirements in Spanish GC are less onerous than German or Italian, which require PVPP to withstand the disturbance with voltage drop down to 20% within 500 ms followed by the voltage restoration to 80% during the next 1 s. The USA GC imposes that the voltage drops to zero for the duration of 0.625 ms and then decrease to 15% from the nominal value followed by the voltage recovery to 90% within 3 s. The Australian GC is more restricted than others because it has to increase the voltage to 80% after being drop to zero in the same time of 450 ms. Table-1 shows the LVRT requirement enforced by Italian, German, Spanish, USA, Japanese, and Australian GCs concerning to PV penetration and Danish GC concerning with wind farm but can used for PV system [1].

Table 2**.** LVRT requirements in international grid codes.

GC Country	During Fault		After Fault	
	V_{min}(%)	T_{max}(s)	V_{min}(%)	T_{max}(s)
Germany	0.0	0.15	90	1.5
Italy	0.0	0.2	85	1.5
Spain	20	0.5	80	1.0
Japan >2016	30	1.0	80	1.5
Japan< 2016	30	1.0	80	1.0
Australia	0.0	0.45	80	0.45
USA	15	0.625	90	3
Denmark	25	0.14	75	0.75

A. Restoring active power

Active power is the important part in the electrical system, so after the clearance of the fault, the generation of active power restoration at limit rate is an essential thing. Once the fault is cleared, the reactive power should feed-in immediately and rise to the original value with a limited ramp rate of 20%/s and 10% in case of not disconnected and short disconnection respectively according to German GC [20, 21] while in Spanish code, the PV system should restore the active power smoothly within 250 ms. Danish GC stipulated that if the voltages representing 90% and 1.1% of nominal voltage, the reduction of maximum power must not be greater than 10% [22] whereas the USA PREPA standard requires an immediate increase in active power production of at least 10%/s [23].

B Active and Reactive Power Support with Frequency Variation

Reactive power can be defined as property of the generating units to maintain the voltage level within limits at the PCC. According to USA grid code, the PVPP must work continuously with power factor varying from 0.9 capacitive to 0.9 inductive in case of dynamic and continuous operation at their rated output power. In Germany, the PVPP should be able to operate with power factor in the range of 0.95 lagging to 0.95 leading depending on the voltage at PCC [20, 21]. Table-3 summarizes the reactive power regulations for other countries.

Table 3. Power factor limits in different grid codes.

GC Country	Power Factor (PF)	
	Leading (Cap.)	Lagging (Ind.)
Germany	0.95	0.95
Italy	0.95	0.95
Spain	0.91	0.91
Australia	0.90	0.95
USA	0.90	0.90

During deviation of frequency, the disconnection of PV plant may cause instability and therefore GCs state restrictive actions. For instance, according to Figure-6, the German grid code requires that all PV units have to reduce their active power when the frequency is above 50.2 Hz with a gradient of 40%/Hz of available power. The growth of the active power again is allowed immediately when the frequency is below 50.05 Hz. From another side under 47.5 Hz and above 51.5 Hz, the plant must be disconnected from the grid [21].

CONCLUSION

In this paper, a review of state of the art of LVRT techniques for PV generation systems, which is organized according to the challenges that should be solved, along with an overview of different national GCs technical requirements especially FRT capability are presented for the connection of PVPP to the power grid. Additionally, a Maximum Power Point Tracking (MPPT) algorithm finds the maximum power for the operation of the PV system during variations of solar irradiance and ambient temperature. Three different kinds of MPPT techniques which are used for LVRT are also presented in the paper.

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