



# Solar Photovoltaic (PV) Grid Integration Issues

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## ABSTRACT

High electricity demand, reduction in fossil fuels and increasing demand towards solar energy, the integration of solar photovoltaic (PV) generation in the utility grid is gaining high popularity in India. Many distributed energy resources (DERs) are connected to the utility grid or microgrids with the help of power electronics interface, while interfacing power electronics with microgrids there are valid technical concerns from utilities about power quality and the impact of DG on the low voltage (LV) grid. This paper focuses on India's Current Solar generation capacity and grid integration issues such as voltage, frequency regulation, active, reactive power control and power quality issues.

**KEYWORDS:** DERs, Microgrids, PE interface, Power quality, Active/Reactive Power Control.

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## I. INTRODUCTION

Solar photovoltaic (PV) generation usage is increasing in India; the generation of electricity from solar photovoltaic cells is costly. The govt. of India is offering many subsidies for solar power plants as a part National Solar Mission and also assisting policy regulatory framework in many states. The main advantages of solar grid integration includes improved Power quality, improved grid reliability and less transmission & distribution (T&D) losses etc. The generation of electricity from solar system often suffers from the problems of variability and intermittency. It depends on mainly 3 factors: 1) non controllable variability 2) partial unpredictability and 3) local dependent [1]. These three factors create distinct challenges for utilities and grid operators in integrating solar photovoltaic (PV) generation.

### 1) Non-controllable variability:

Solar power output varies from time to time because available sunlight is not constant throughout the day as it changes from sec to sec or moment to moment on time scale. This fluctuation causes unbalanced output power so that it requires additional energy to balance supply and

supportive actions such as frequency regulation and voltage support. Frequency regulation occurs on seconds-to-minutes basis, and is done through automatic generation control (AGC) signals to generators. Voltage support: generators used for reactive power to raise voltage when necessary; additionally, grid operators must track loads-demand for electricity on the consumption side of the grid and ensures that generation matches load at all times. This load following function becomes particularly important at times of day when demand for electricity increases substantially, such as morning, a hot afternoon or evening. Load following may be provided through a class of supportive service.

The integration problems are harmonics and subsynchronous resonance, However, high penetrations of solar generation will add more variability to the energy system It is more difficult; to manage such problems at the device level, so it requires supportive technologies and strategies to maintain grid balance.

### 2) Partial unpredictability:

The Sunlight availability is partially unpredictable. Solar PV systems require the presence of sunlight in order to operate. Unpredictability can be

managed through weather monitoring technologies such as SOLARGIS software. The utilities have to maintain reserve capacity to provide additional power when solar generation produces less energy than predicted, and dispatchable load to consume excess power when solar generation produces more energy than predicted.

Partial unpredictability is similar to uncertainty and is distinct from variability. The variability of sunlight affects the system at the moment-to-moment time scale as a cloud passes over a PV plant.

Partial unpredictability refers to inability to predict available sunlight as it varies from time to time. The grid operators must manage this uncertainty through "Unit Commitment". Unit commitment means the process of scheduling the generating units at every hour interval with varying loads under different constraints sometimes actual generation does not match the demand in that case the grid operator must balance the difference. Unit commitment must be acceptable for reliable/flexible operation so that it has to run cost effectively.

### 3) Location Dependence:

Solar generation is possible where solar resource locations are identified and it is not transported to the generation site like coal and oil. PV generation must be co-located with the resource itself. New transmission capacity is often required to connect solar resources to the rest of the grid. Transmission costs are especially important. The available sunlight is outside of the human control, integrating solar generation resources into the electricity grid involves many risks to the grid operators that may affect many other parts of the grid, including conventional generation. These operations and activities occur along a multitude of time scales, from seconds to years, and include new dispatch strategies for rampable generation resources, load management, provision of supportive services for frequency and voltage control, expansion of transmission capacity, utilization of energy storage technologies, and linking of grid operator dispatch planning with weather and resource forecasting [1]. Because of this intermittency solar photovoltaic (PV) grids require voltage and frequency support for the grid integration. In addition it requires active and reactive power control.

## II. SOLAR ENERGY (PV) SCENARIO IN KARNATAKA AND INDIA

India is currently witnessing a transition in its solar market. The initial emphasis was on large scale, grid connected projects driven by the Gujarat state solar policy-2009, National Solar Mission -2010 and policies of other states, namely Karnataka, Rajasthan, Andhra Pradesh, Telangana and Tamil Nadu. Subsequently, net-metering policies that have been announced by nine states in India focus on distributed solar. [2][3].

India's total installed capacity of solar power has crossed the 5GW mark. The total commissioned utility solar capacity in the country stands at about 4.7GW, while rooftop capacity is 525 MW according to Bridge to India, a solar energy consulting firm. Solar capacity crosses 5000 MW as on 15-01-2015 during last fiscal, a total capacity of 1,112 MW of grid connected solar power projects and 44.5MW of rooftop projects were installed for the current fiscal, 827 MW of solar capacity has been added so far.

Government of India has put a target to achieve 100 GW of solar power by 2022 as of today the country has a solar project pipeline of 15.7 GW. The fiscal year 2016-17 will be Indian solar market's transition year annual capacity addition could top 6 GW with India becoming one of the leading solar nations globally [2]. The geographical location of India is quite favorable for implementation of solar energy technologies. Present solar energy utilization in India stands far from being adequate. From this perspective, India has formulated its solar energy utilization roadmap for future through Jawaharlal Nehru National Solar Mission. With a target of deploying 20GW of grid connected solar power generation by 2022.

### Status of Karnataka State Solar (PV) Energy:

The Karnataka state has good solar radiation of 5.4 to 6.2 kWh/m<sup>2</sup>/day. And it was the first state in south India to announce its solar policy in 2011 and now it was revised as "The Karnataka solar policy 2014-2021". The Karnataka Electricity Regulatory Commission (KERC), on 10th October 2013, announced the tariffs for grid-connected solar PV projects. The tariff order specifies the benchmark tariffs for grid connected solar PV and rooftop and small solar plants (with and without Ministry of New and Renewable Energy (MNRE) subsidy)[4].

Meanwhile, more recently the Government of Karnataka has finalized a new solar policy [5] on 22nd May 2014 which will be effective until 2021.



Among other things, it aims to promote solar rooftop generation with a target of 400 MW, both through net metering (with a focus on self-consumption) and gross metering (based on KERC tariff orders). For net metering, surplus energy injected into the grid will be compensated by the utility at KERC determined tariffs. For grid connected rooftop, all eligible consumers can set up projects within the prescribed capacity limit. Additionally, projects would also be allowed on third party roofs [2]. Tariff for different RES is tabulated here [6].

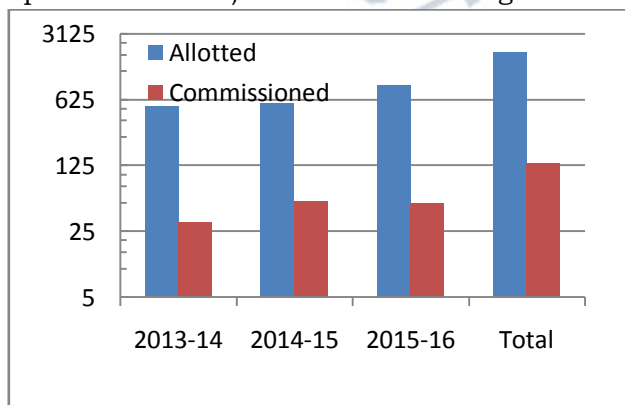
**Table.1**

**Tariff for Renewable Energy Projects in Karnataka**

|   |               |
|---|---------------|
| Wind  | Rs.4.50/Unit  |
| Small Hydro(Levelised over 35 year life of the project) | Rs.4.16/Unit  |
| Solar   |               |
| Solar Photo Voltaic                                     | Rs.6.51/Unit  |
| Solar Thermal   | Rs.10.85/Unit |
| Roof top small solar Photo Voltaic                      | Rs.9.56/Unit  |
| Roof top small solar PV(with 15% capital subsidy)       | Rs.7.20/Unit  |

The government of Karnataka proposes to install 2000MW of solar power by 2021 and is trying to achieve minimum 3% of energy consumption from solar out of total energy consumption. It is proposed to achieve minimum 1600MW of Grid connected solar power and 400MW of roof top grid connected solar generation in the state by 2018.

**Net Metering:** Net Metering allows the solar project owner to feed the excess solar power to grid when the load available is low, say, during weekends in office/college buildings. The excess power fed is offset against the electricity used from the grid in the electricity bill. Year wise Solar Energy Projects Progress Report (Since inception up to 31.03.2016) in MWs shown in fig.1



**Figure 1 Year wise Solar Energy Projects Progress Report**

Total allotted solar projects are 1994MWs in that total commissioned are 134MWs up to 31.03.2016 from inception.

#### *The Setting Up Of the Solar Energy Corporation of India:*

- The mandate of the Solar Energy Corporation of India (SECI) allows wide-ranging activities to be undertaken with an overall view to facilitate the implementation of the National Solar Mission and the achievement of targets set therein. The SECI has the objective of developing solar technologies and ensuring inclusive solar power development throughout India.

#### *State Initiatives:*

- State Electricity Regulatory Commissions in Andhra Pradesh, Haryana, Punjab, Madhya Pradesh, Maharashtra, Rajasthan, Tamil Nadu, Gujarat, Kerala, Punjab, Orissa and West Bengal have announced preferential tariffs for purchase of power from wind power projects.
- New Solar Policy in 2015 - Telangana and Andhra Pradesh.
- New Solar Policy in 2014 - Karnataka and Rajasthan.

Incentives offered by The Government for the Development of the Solar Energy Sector [7] Include:

- Exemption from excise duties and concession on import duties on components and equipment required to set up a solar plant.
- A 10-year tax holiday for solar power projects.
- Wheeling, banking and third party sales, buyback facility by states.
- Guaranteed market through solar power purchase obligation for states.
- GBI schemes for small solar projects connected to a grid below 33KV.
- Reduced wheeling charges as compared to those for conventional energy.
- Special incentives for exports from India in renewable energy technology under renewable sector-specific SEZ.
- A payment security mechanism to cover the risk of default by state utilities/discoms.
- A subsidy of 30% of the project cost for off-grid PV and solar thermal projects.
- Loans at concessional rates for off-grid applications.

### III. GRID INTEGRATION ISSUES

The higher penetration of intermittent solar PV energy system has introduced many technical issues, including power quality, reliability, safety and protection, load management, grid interconnections and controls, new regulations, and grid operation economics [2].

#### A) Connection Issues:

In the power grid is currently the electric power flows from the higher voltage grid to the lower voltage grid. Increased share of distributed generation units may lead to inducing power flows from the low voltage into the medium-voltage grid. This bi-directional power flows asks for different protection schemes at both voltage levels. Moreover, the added flexibility of DG asks for extra efforts on the grid operation side. As some customers might want to switch to the "island" mode during an outage, they should also meet the requirements for such operation mode. Next to guarantying no power supplied to the grid, they must be able to provide the supportive services needed. Moreover, once the distribution grid is back into operation, the DG unit must be able to be re-synchronized.

Technical recommendations like G83/1, G59/1, IEEE 1547 [9], CEI 11-20 prescribe that DERs should be automatically disconnected from the medium voltage (MV) and low voltage (LV) utility distribution networks in case of tripping of the circuit breaker (CB) supplying the feeder connected to the DER. This is known as the anti-islanding feature. This is incorporated as a mandatory feature in the inverter interfaces for DERs available in the market. As the DERs are not under direct utility control, use of anti-islanding protection is justified by the operational requirements of the utilities. However, it drastically reduces the benefits of DERs and microgrids improve the service reliability. Therefore, these issues must be critically assessed and resolved, and market participation of DERs and microgrids should be allowed to exploit their full benefits. Although the current power scenario is still quite conservative in providing strong aspects to this new technology, the designers of distribution expansion are trying to realize the full capacity of the distributed generators and microgrids. The utilities may be pressed in this regard to come forward to encourage DER and microgrid deployment from three probable directions, as follows:

- As microgrid owners and DER manufacturers are more comfortable with basic energy production, they would intend to expand their range of operations.
- State regulators would press utilities to accept greater DER penetration.
- ISOs would recognize that microgrids and DERs can sell several supportive services in the open market.

Hence, state regulatory bodies need to take initiatives for rapid implementation of the new technology for greater benefits to the distribution systems [10].

#### B) Voltage Control (no load THD<3.5%)

Balanced and unbalanced voltage fault conditions

Strong and weak grid conditions

Voltage magnitude modulations

#### C) Frequency Control

Fast output frequency control  $\pm 3\text{Hz}$  to simulate frequency response of various power systems 50/60 Hz operation.

#### D) Power quality

Apart from large voltage drops to near zero (reliability problems), one can also have smaller voltage deviations. The latter deviations are aspects of power quality. Power quality refers to the degree to which power characteristics align with the ideal sinusoidal voltage and current waveform, with current and voltage imbalance [11]. Thus, strictly speaking, Power quality encompasses reliability. Insufficient Power quality can be caused by failures and switching operations in the network (voltage dips and transients) and by network disturbances from loads (flickers, harmonics and phase imbalance).

### IV. REMEDIES TO GRID INTEGRATION ISSUES

#### A) Frequency Measurement:

A very fast and accurate method of frequency measurement is presented using a Digital Signal Processing (DSP) based technique. Here, the digitized values of the voltage samples taken at a specified sampling rate are considered for measurement. This method is claimed to provide a correct and noise free estimate of near nominal and off-nominal frequencies within the time span of 25ms using phase locked Loop (PLL) [12][13]. The basic PLL comprises of a phase detector, a loop



filter and a voltage controlled oscillator (VCO). The phase detector compares the input signal with the output of voltage controlled oscillator; a loop filter helps in filtering out the output from phase detector and VCO is an oscillator in which the output frequency deviation is proportional to the input signal.

#### *B) Voltage and frequency control:*

Various researches have been done to investigate the voltage control methods with DERs in grid connected mode and both voltage and frequency control methods in islanded/autonomous microgrids. The microgrid voltage and frequency control can also be performed using the same principles as traditional droop control methods[14][15][16]. The real and reactive power control based on adaptive droop controller is used in [16]. This work uses the frequency locked loop based on second order generalized integrator (SOGI-FLL) in order to measure voltage and current phasors.

In [17] a voltage power droop/frequency-reactive power boost (VPD/FQB) control scheme used which is capable of controlling multiple Voltage Source Converters (VSCs) to operate in parallel.

Another method is based on dq-frame current control scheme. This work utilizes the built-in-phase locked loop in the DER system for synchronization to the grid voltage. The importance of shunt connected voltage source inverter (VSI) with PV generator in order to compensate for the voltage sags in the grid connected mode is explained in [18].

PI controller that improves the stability of the system through the low-pass filtering function. PR controller could effectively reduces the 2<sup>nd</sup> ripple in PWM inverter DC side voltage and could reduce harmonic content of PWM inverter AC side current.

Since PE converters [8] comprise of many switching components, the efficiency can be increased if the switching losses are minimized. As compared silicon based MOSFET switches, Silicon Carbide (SiC) based switches offer very less switching as well as conduction losses and have an ability of operating at higher temperature [19]. With these and several other advantages over silicon, silicon carbide has a very promising future to be used in manufacture of switches used in the PE interfaces for integration of DERs.

Shunt Active power Filter (APF) is used to compensate for the harmonics and reactive currents caused due to the non-linear loads. The removal of the harmonic distortion of the grid

voltage can also be achieved by the combination of using the resonant harmonic filter and injecting the local voltage signal the same amount of distortion [20]. This method helps in removal of harmonic distortion even at low quality factor (Q).

## V. CONCLUSION

The different grid integration issues and mitigation techniques were discussed in this paper. Karnataka state solar policy 2014-21, tariff structure mentioned here and many initiatives have taken for deployment of solar PV microgrids in the state. For effective operation of PV Microgrids, the intermittency and variability can be predicted using SOLARGIS software and PV system software and performance of PV system can be analyzed in MATLAB/SIMULINK.

## VI. FUTURE WORK

The grid integration issues were discussed so far, further in my research the PV grid integration issues mitigation techniques by using PI Controllers and PR Controllers will be analyzed using MATLAB/ SIMULINK.

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