Effect on Synchronous Generators Due to Intermittency of Solar Power in a PV: Grid Integrated Power System

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Abstract. With the introduction of renewable energy sources, the existing power system is being affected. The power flows are not meeting the requirements due to the intermittent nature of renewable energy sources. Therefore, it is significant to calculate their effects on the power system components prior to their large integration into the Grid. In this paper, the effect of the large power integration of Photo Voltaic (PV) sources is analyzed. A typical power system model is considered for the analysis. Four different featured generators with two PV power sources are considered whose output is varied. The ramping rates of the generators are calculated for the prescribed conditions. The data considered are mere to the real data. Simulink model is developed to find the effect. It shows that, there is frequent ramping rates on the conventional generators due to the intermittent nature. The ramp up/down impacts the performance of the generators. There is a necessity of quick acting generators to keep the system stable. This paper also identifies the necessity of ancillary services having higher ramping rates.

Keywords: Frequency regulation · synchronous generators · PV power · intermittency · ancillary services

1 Introduction

In the recent years, there is a huge deputation of solar panels across the world due to various reasons like eco-friendly, renewable, localized generation and easy installation. The major motivating factor towards large integration of solar power plants into the grid is to reduce carbon emissions. Hence there is a rapid deployment of these sources. Meanwhile, the power system with these inverter-based power plants is being affected in terms stability, power management and curtailment of the existing power plants due to their intermittent nature. In India the injection of power from these sources is around 90,399 MW, which is of 20% of the total generation on a particular day. As the injection of power from the solar increases, the power system will be affected in its present form. Many researchers have found that the stability of the power system is a major concern. A part from this issue, the authors from [1–10] mentioned many issues like reversal of power, reactive power support, harmonics, islanding and increase in fault level, decrease

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in short circuit ratio (SCR) with the upcoming of solar power plants. In spite of these issues, it is necessary to integrate the large amount of solar power into the existing grid to prevent us global warming and from other consequences.

Thorough studies are made by the utility agencies to find out the real time effects on the existing grid. In India, Power System Operation Corporation (POSOCO) along with National Renewable Energy Laboratory (NREL), USA made a clear study on the effect of 50% of solar power penetration into the Indian grid. The study was made on each region of the Indian grid. It was found that there is shortage of ancillary services which are helpful to maintain the frequency during transients. Also, identified that the net load of the system has many peaks and depths. It was found that the net load in eastern region and southern region has more slopes and less generation during the peak period. Also, the study identified that local changes in ramping rates is most severe. The research also explored that the daily peak – valley ramp increment by 47% i.e., 37 GW.

The ramp rate of a generator is to change is its capacity to change the output within the considered time. It is calculated as percentage (of unit rating) in a minute. As we know that the fossil fuel-based power plants will contribute major part of the load demand. The effect on these power plants is to be studied carefully. It was estimated that the maximum All India load Ramp up/Block (15 min) is 3750 MW and downward ramp rate is 2500 MW for the year 2017–18. As day by day the load and penetration of renewable energy is increasing, theses ramping rates will get further affected [11].

Few of the coal-based power plants are going to get shut down according to National Electricity plan, 2018 due to various reasons. So, there must be an attention to be made in maintain the balance reserves or ancillary services. CERC, Indian Electricity Grid Code, 2010 define the ancillary services [12].

To find out the ramping rates on thermal plants, a power system model is considered in this paper. The design of the model is explained in subsequent sections of the paper. A comprehensive study is made and the simulation results are shown. This paper also verifies the power sharing of each synchronous alternator.

The paper is organized as follows. Section 2 describes the generalized frequency regulation methodology in conventional power system. Section 3 gives the Grid codes that are to be implemented for large PV penetration. The proposed method of simulation study and analyses is made in Sect. 4. Simulation results are described in Sect. 5 and the last section concludes the paper.

2 Frequency Regulation in Conventional Power System

As we know that frequency is the key parameter in grid security. During a power system contingency, the mechanical features of conventional generators will help in maintaining the stability. The rotational inertial energy of the turbines will assist for maintain the stability for few cycles. Immediately the Automatic Governing Control (AGC) will set the reference power to each generator to maintain the stability. The time duration of the governing action is shown [13]. Scheduling of power is done for fifteen minutes. Based on the power available and market prices the scheduling of power takes place by the agencies. But every generating unit has its own limitation on their ramping capabilities which is mentioned in Table 1. It is a big practice and planning to schedule the

Table 1. Ramping rates of different power plants

Method of Generation/Power Plants	Minimum Loading (%)	Ramping Rates (%/min)
Coal power plants	55–60	1–2
Super Critical Power Plants	40	3
Nuclear power plants	55–60	1–5
Gas Combustion plants	50	22–25
Combined Gas Turbine plants	50	2.5–3
Hydro Storage power plants	33	50
Battery Energy Storage	0	20

power between the generators with proper coordination for balancing the grid. With the induction of renewable energy sources, the grid stability is being affected due to the unavailability of frequency regulation methods automatically.

2.1 Governor Control

Figure 1, gives the turbine governor model of a synchronous generation. In the figure, $\Delta P_c(s)$ is the power command given by the turbine, $\Delta P_G\ (s)$ is the power delivered by the generator and $\Delta P_D\ (s)$ is the load demand. *R* represents the speed regulation of the governor which is given by the Eq. (1):

$$\Delta f = -R\Delta P_D \tag{1}$$

When there is change in load in the system, frequency deviation occurs depending on the droop characteristics and frequency sensitivity of load. In a grid, the change in any part of the load will be shared by the generators which are on speed governing. This frequency restoration requires some action which adjusts the load reference point (through the speed changer motor). This phenomenon continuously takes place as the system load is dynamically changing. The participation of the generators in the frequency regulation is sophistically implemented area wise. The Automatic governor control of that area will respond to the load changes in that area, by calculation Area Control Error (AEC).

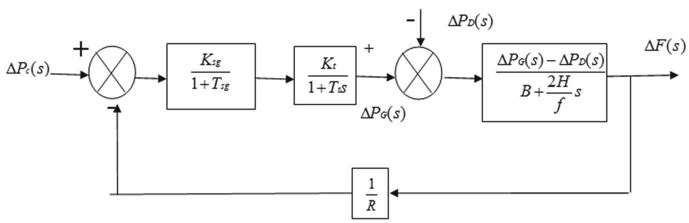

Fig. 1. Turbine-Governor model of a conventional system

During some abnormalities, one or more areas cannot correct the frequency deviation due to insufficient generation or mismatch, during that time other areas will assist permitting the interarea power transfer. But each area will assist in frequency regulation in proportion to its regulating capacity.

3 Regulatory Requirements for Stability Maintenance in Power System

The Regulatory commission has made the following instructions in order to maintain the stability in the Indian Grid due to the penetration of DER's. As per IEGC/CEA technical standards, there must be droop setting which is in between 3%–6% for thermal synchronous generators. Also, there must be a droop setting of 0–10% for hydro synchronous plants.

Coming to the secondary reserves, each region should maintain adequate secondary reserves in comparative to the highest generation unit of the regions. It was found that, 1000 MW in Southern region; 800 MW in Western region; 800 MW in Northern region; 660 MW in Eastern region and 363MW in North-Eastern region (total approx. 3600 MW on an All India basis) of generating units need to be maintained. Automatic Generation Control (AGC) is to be implemented which is a part of operating secondary reserves whenever necessary to maintain the frequency in the system and also achieve targeted power flows from the units. Hence, a reliable, sophisticated telecommunication network and protocols need to be developed to achieve the above targets [11].

Apart from the secondary reserves, de-centralized tertiary reserves of at least 50% of the largest generating unit must be maintained by each state control area. Tertiary control is to change manually for dispatching and unit commitment to restore secondary control reserve. It was identified that about 4900 MW capacity tertiary reserves to be maintained in the Indian grid.

The regulatory committee also recommended, a 55% of Maximum Continuous Rating (MCR) to operate the Central Generating Station of inter-state Generating Station for the system to be stable and face the contingencies immediately. It also recommended to verify the ramping rates i.e., ramp up and ramp down rates for flexibility [14].Reactive power support is a major issue as most of the solar power plants will inject active power only. But it will be great advantage if there is a reactive power support from the solar power plants. The governor action will be slightly time consuming when there is a voltage dip due to faults whereas the inverter can quickly inject reactive power if there is a necessity to bring up the grid voltage. It helps in under voltage contingencies without loss of generation and also prevents from under voltage relay tripping. Overall, impact of reactive support is more on nearby fault than the distant located generators [15] (Fig. 2 and Table 2).

4 Proposed Methodology

The proposed system consists of 4 synchronous generators as shown in Fig. 3. Two PV sources are integrated into the system whose output is intermittent in nature. Other components like transformers, line reactance is considered as per the standards. The PV

Table 2. Reaction time of the reserves during contingencies

Reserve	Quantum (MW)	Duration
Primary	4000	2–5 s
Secondary	3600	5 s to few minutes
Tertiary	4900	Few min – hours
Total	**12500**	

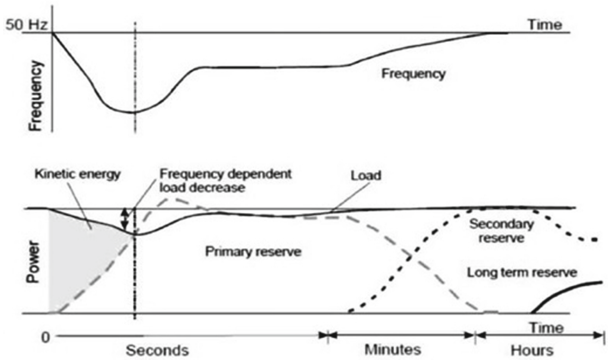

Fig. 2. Spinning Reserves

system is designed to extract the maximum power available. A Boost converter is used to track the maximum power. The inverter control is achieved by synchronous reference frame theory and cross coupling methodology. The DC bus voltage is maintained constant during the appropriate availability of insolation and disconnect from the circuit when there is no irradiation.

The following Table 3 provides the system parameters which are significant for the study.

5 Simulation Results

The dynamics of the system is measured by increasing the load in the system at 1 s simulation time. The output from the PV is almost reduced to zero to find its effect on the synchronous generators and frequency of the system. The system is balanced for all disturbances and power variations in the system. After 3 s, one of the PV power outputs is made to zero. The variations in the power output from the generators is shown the simulation results.

The below Fig. 4 represents the output from all the generators. It is observed that at t = 1 s, the power from the PV1 is reduced to zero. It is observed that the output from the generators is increased automatically to meet the demand based on their governor action. At t = 1.9 s, the load is increased suddenly. The generator 1 output has reached

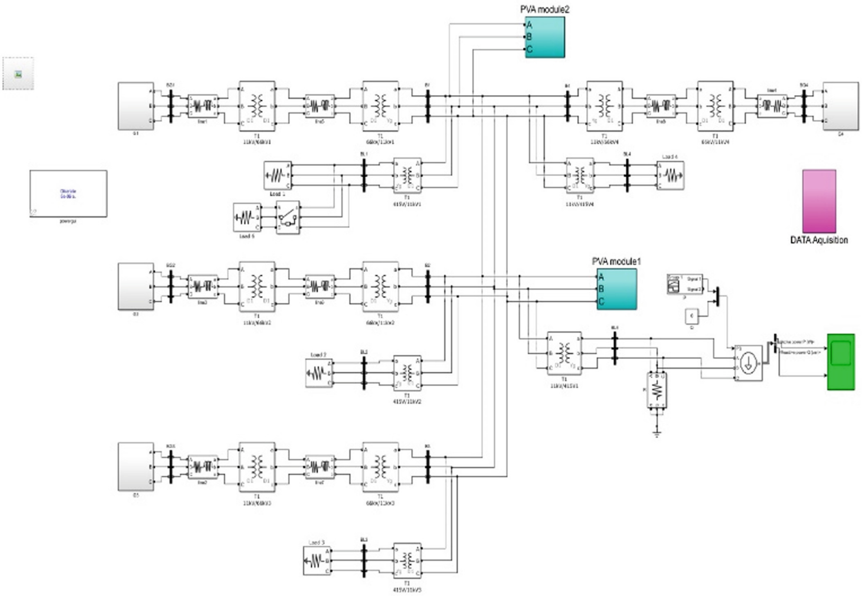

Fig. 3. Simulink model of the proposed system

Table 3. System parameters

S. No	Type of the Component	Rating	Limits
1	Gen. - 1	250 kVA, 11 kV	P = 200 kW and Q = 150 kVAr
2	Gen. – 2	250 kVA, 11 kV	P = 200 kW and Q = 150 kVAr
3	Gen. – 3	85 kVA, 11 kV	P = 68 kW and Q = 51 kVAr
4	Gen. - 4	60kVA, 11kV	P = 48 kW and Q = 36 kVAr
5	PV - 1	97 kW	
6	PV -2	20 kW	
7	Load		

to its maximum limit, hence its output is not changed and got settled at approximately 150 kW only.

the generator 2 delivers more power to the load than other generators. At t = 3.1 s, load of 170 kW is removed to observe the power sharing capability of the system. The At 3.5 s, the PV1 insolation is increased and it takes the load which shows the MPPT control strategy delivers the maximum power to the load for its effective use. The Fig. 5 shows the change in mechanical input of generator 2 based on the system dynamics (Table 4).

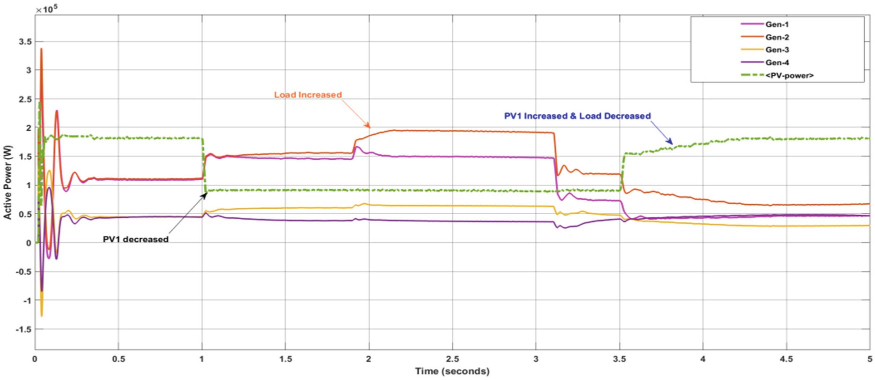

Fig. 4. Output from all the generators sharing the load when PV1 is absent at t = 1s

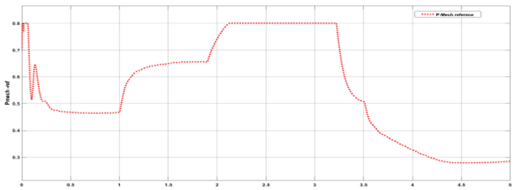

Fig. 5. Change to mechanical output of 2nd Generator

Table 4. Ramping rates of the Generators

S. No	Type of the Generator	Max. Output setting	Output (kW) before change in PV output	Output (kW) After change in PV output	Ramp rate
1	Gen. 1	200 kW	188	188	0
2	Gen. 2	100 kW	58	91	0.46 MW/sec
3	Gen. 3	68 kW	25	48	%1.%2 W/sec

6 Conclusion

Due to the intermittent nature of the photovoltaics, the power stability is has a major concern. The frequency regulation methods should meet the requirements proposed by the agencies strictly to cope with the upcoming renewable energy sources. This paper clearly shows the effect on the synchronous generators when there is a sudden change in the output power from the renewable energy sources. The power sharing of each generator is shown clearly. But there is always stress on the synchronous generators. Therefore, there is a need of Regulatory Reserves Ancillary Services (RRAS) in the grid to meet the ramping rates and keep the system stable.

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