# A Comparative Study of System Frequency Model in Between System Frequency Model and Spinning Reserve Technique

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***Abstract-*** *Integrating large scale solar photovoltaic generation plants with electric power systems as a renewable energy source achieve many targets, i.e. economic, environmental and technical. These plants are classified as variable renewable energy sources which have two main attributes; variability and uncertainty. This variable nature poses challenges for an electric grid that has traditionally been powered by traditional generating resources that are relatively stable and controllable.*

*This paper emphasizes on comparative study of system frequency of a large scale PV power generation in case of system frequency model, demand response and spinning reserve technique.*

*Simulation studies are conducted to analyze the response of the system frequency of large scale PV power generation in both possible solutions like system frequency model and spinning reserve technique.*

***Keywords***- System frequency model, demand response, spinning reserve technique.

## I. INTRODUCTION

Solar energy, with all of its advantages as a sustainable energy source, has become a promising solution for the future power demand. In recent years, the generation capacity of PV power installed in many countries around the world has been increasing rapidly from kilowatts to megawatts. However, due to the intermittent nature of PV power generation, the large scale integration of PV will compromise the reliability and stability of the distribution network as sudden changes in the weather will drastically reduce the generation from its maximum output [1].

Despite of Integrating SPVG achieves many targets, but there are two major attributes of Solar Photovoltaic generation SPVG that notably impact system operations.

The first is the variability (generation changes according to the availability of the primary fuel i.e. global solar radiation in this case resulting in swings of the plant output). The second is the uncertainty. [2]

System frequency problem caused by PV power generation has not been thoroughly investigated in previous research works [3]. The main reason for ignoring this problem is that the PV power generation usually accounts only for a relatively small portion of the total power generation in a power system[4-7]. Therefore, the intermittency of PV power generation will only have little effect on the system frequency because of the relatively large system inertia of the grid.

Such challenges can be met with system frequency model and spinning reserve technique [11-13].

The following task has been conducted in this paper

- A system frequency model has been proposed.
- Spinning reserve technique is defined to save the grid from blackout.
- Comparison of system frequency in both the above cases.

## 1. SYSTEM FREQUENCY MODEL

In a power system, the relation between real power generation and consumption is linked to system frequency. Since the system frequency is directly related to the rotating of the online generators, the input mechanical power and the inertia of the online generators are very important parameters when analyzing system frequency.

Accordingly, in traditional power system networks, the system frequency is linked to the real power generation of the online generators and the real power consumption of the loads. However, the PV power generation accounts for a relatively high penetration in the research, hence the relation of the real power generation and consumption should also take into consideration of the PV power generation. power generation and consumption should also take into consideration of the PV power generation. online generators and the real power consumption of the loads. However, the PV power generation accounts for a relatively high penetration in the research, hence the relation of the real power generation and consumption should also take into consideration of the PV power generation.

The system frequency model for the smart grid network can be shown in Fig. 1.

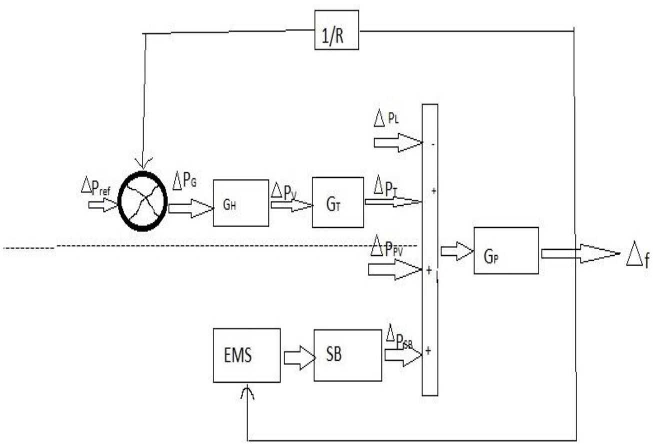


Fig. 1. Proposed system frequency model

Mathematical expression can be given as

$$G_H(s) = \Delta P_v(s) / \Delta P_g(s) = 1/(1+sT_H) \quad (1)$$

$$G_T(s) = \Delta P_T(s) / \Delta P_v(s) = 1/(1+sT_T) \quad (2)$$

$$G_P(s) = K_P/(!+sT_p) = (1/D)/[1+s(2H/f_0D)]$$
$$= f_0/(f_0D+2sH) \quad (3)$$

$$\Delta f(s) = G_P(s)[\Delta P_T(s) + \Delta P_{PV}(s)$$
$$+ \Delta P_{SB}(s) - \Delta P_L(s)] \quad (4)$$

### A. MPC ALGORITHM

An MPC algorithm is used in this research because of its advantages in the control of inverters. Discrete control algorithms usually require less computational resources which is why industries tend to use them rather than continuous control algorithms. MPC is a digital control scheme which can be used by most digital controlled power electronic devices.

MPC algorithm can generate control signals by minimizing cost function. The cost function is set as below

$$J = (R_s - Y)^T (R_s - Y) + \Delta U^T \overline{R} \Delta U \quad (5)$$

Subject to

$$u_1 + u_2 = 1; u_1, u_2 \in \{0,1\} \quad (6)$$

From (5) it is seen that when the cost function is minimized, the errors between the reference and output signals and the deviation of the output signals can be controlled at the same time.

### B. ENERGY MANAGEMENT SYSTEM

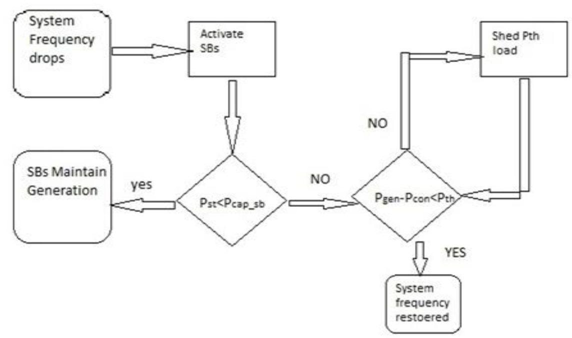


Fig.2. Energy management system

At the time of system frequency problem in the power system, traditionally the online generators will generate more power. Because of the increase in the real power generation, the electric torque in the rotors will increase, reducing the rotating speed of the rotors. Therefore, the system will reach a new steady state with the system frequency below the nominal value. To avoid operating in under-frequency situation, a new strategy is proposed for EMS using SBs and demand response to solve the problem.

From Fig.2. It can be seen that when a system frequency problem occurs in the smart grid network, the SBs will be activated to supplement the required real power to the system. Through smart meters, the EMS will control whether the capacity of SBs is enough to surpass such a real power shortage. If it is not sufficient, demand response will be activated. The EMS will shed *Pth* of load each time until the shortage is within acceptable range.

### 2. SPINNING RESERVE TECHNIQUE

The spinning reserve can be defined as the unused capacity which can be activated on decision of the system operator. Spinning reserve is provided by devices which are synchronized to the network and able to affect the active power.

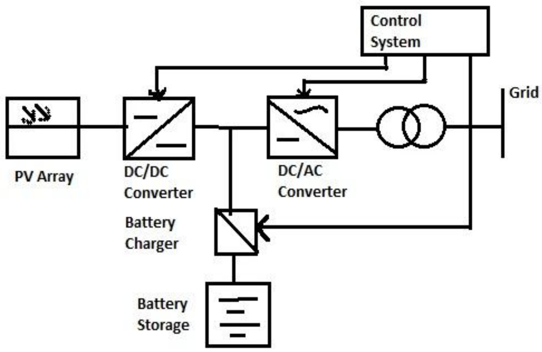


Fig.3. Grid connected PV generator structure

The typical structure of a grid connected PV unit is shown in Fig. 3. Its main components are the PV array, the DC/DC, DC/AC converters and the associated (converter and overall system) controls.

System operators normally have access to a range of operating reserves that control active and reactive power through the grid. Spinning reserve can be classified as follows:

1- Positive spinning reserve is the on-line reserve capacity that is synchronized to the grid system and ready to meet electric demand within acceptable predefined time frame.
2- Negative Spinning Reserve is the capacity that can be switched off quickly to compensate a dip in generated energy (e.g. Load Shedding).

The frequency fluctuates when there is a change in the production of, or in the demand for energy. If a generator trips, the frequency will decline. Depending on the prime mover and spinning reserve, the frequency will eventually go back to its desired value as Fig.4.

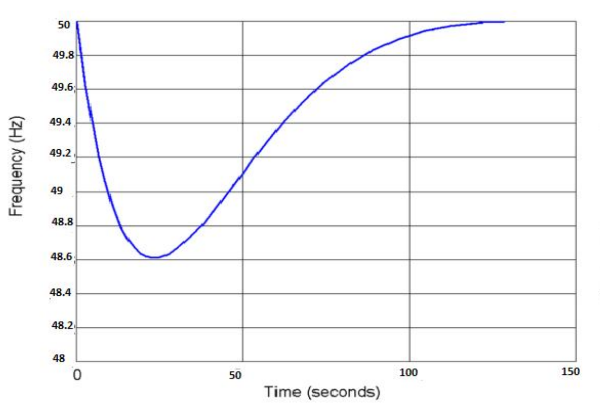


Fig.4. Frequency change with sufficient spinning reserve

**A. FREQUENCY BEHAVIOR DURING OVERLOAD**

Large scale SPVGs have significant impacts on the operation and stability of electric power systems. To examine the frequency behavior and response of SPVGs integrated with complicated power systems during overload conditions, a multi machine system WECC, three-machine, nine-bus test power system described in is tested.
The system inertia is considered as one of the critical system parameters. The inertia of the rotating masses of the synchronous generators and the turbines governs the immediate frequency response with respect to inequalities in the overall power balance.

When a frequency disturbance occurs, the synchronous machines will inject or absorb kinetic energy into or from the grid to counteract the frequency deviation. The lower this system inertia, the more jumpy the grid frequency reacts on abrupt changes in generation and load patterns.

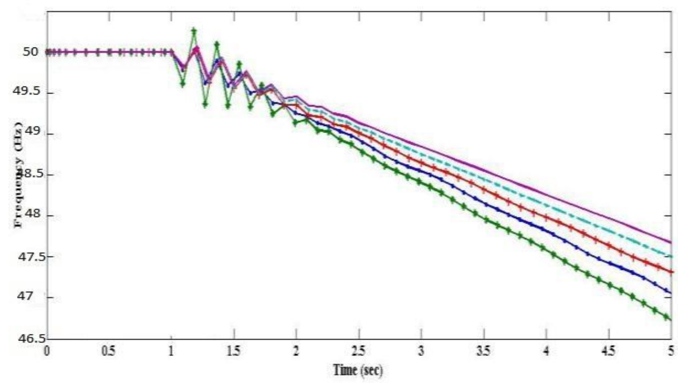


Fig.5.Frequency behavior during overload

Due to the inertia effect, a synchronous generator has inertia constant H = 12, largest inertia, its frequency decays from 50 Hz to 47.67 Hz over 4 sec after the over load event. While, the frequency decays to 46.75 Hz in the inertia less SPVG case after the same period as shown in Fig. 5.

An index called Time of Fall $t_{fall}$ is suggested to classify the frequency decaying behavior according to its severity. Time of fall is defined as the time interval for the system frequency to decay from the nominal frequency 50Hz to the lower acceptable limit 49.5 Hz. Each case has a specific time of frequency fall according to system characteristic.

PV generators frequency response has the highest rate of frequency decaying. It makes the over load more severe than traditional synchronous generators. Therefore, PV need adequate spinning reserve scheme to prevent rapid uncontrollable under/over frequency behavior.

After the over load event, Synchronous generators is releasing part of their stored kinetic energy immediately. This released energy damps frequency variation and eliminate power mismatch between generated power and demand power.

Constant impedance loads are less severe than constant power ones. Dependency of demand power on voltage and frequency, in constant impedance case, reduces the gap between the generated and demand powers. Therefore, the frequency behavior is better in constant impedance model than constant power one.

## 3. COMPARISON OF SIMULATION RESULTS

### A. SYSTEM FREQUENCY MODEL

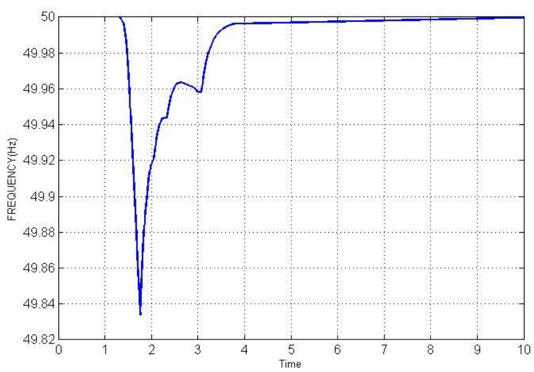


Fig.6. Frequency response

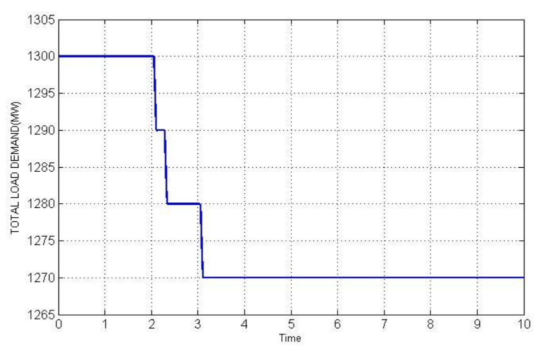


Fig.7. Demand response

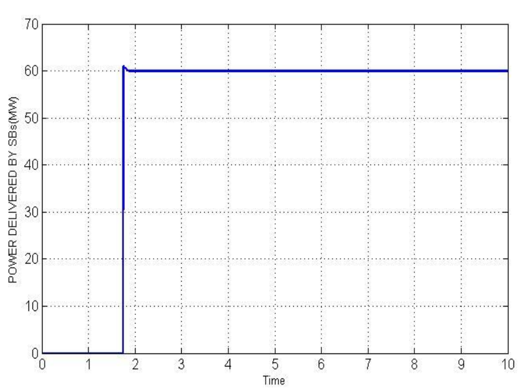


Fig.8. Power supplied by storage batteries

The system frequency starts to decrease as shown in Fig.6 because of insufficient power. There is a delay in the system frequency drop because of the presence of system inertia.

At t=1.79s, the SBs are activated to supply real power to the smart grid network as shown in Fig.6. At that time the system frequency has dropped to 49.84Hz as shown in Fig.6. As shown in Fig.8, when SBs reach to its maximum output i.e 60MW then starts supplying power.

As SBs are unable to supply fully the shortage real power, the system frequency cannot be restored back to normal operating range of 50±0.02Hz. According to the strategy mentioned in previous section, the demand response will be activated. From Fig.7 it's seen that EMS controls the system to shed 10MW in 3 intervals of time. After shedding the load demand decreases to 1270MW, for which the system frequency gradually restored back to nominal range as shown in Fig.6, by activating the SBs and demand response.

### B. SPINNING RESERVE TECHNIQUE

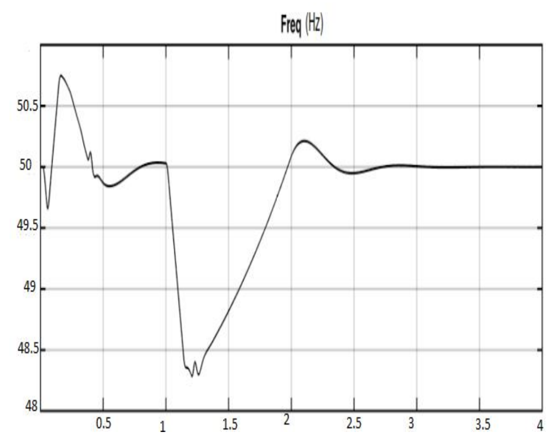


Fig.9.Frequency response after overloading

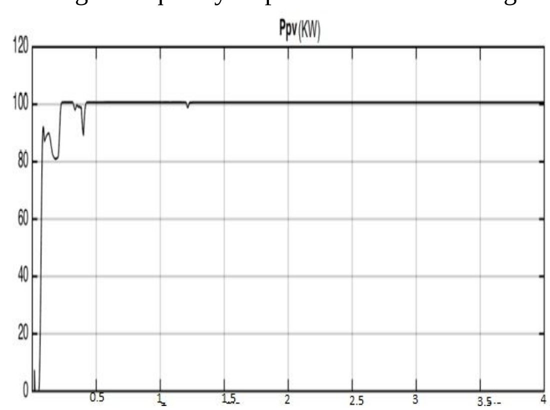


Fig.10. Active generated power of PV

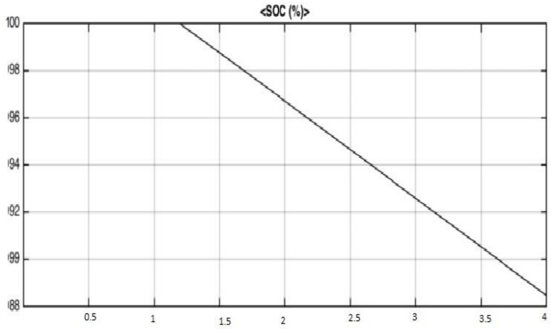


Fig.11. SOC of SBs

Figure 9 shows the system response after using BESS. As shown in Fig. 9 and Fig.10 the PV output power is constant during the variable behavior of system frequency.

SB is connected after severe over load at frequency equals 48.3 Hz as shown in Fig.11. Notably, SOC is decaying after connecting to the system. SB compensates needed energy during 1.3 sec and recovers system's frequency to acceptable limits as shown in Fig.9.

Therefore, it is recommended to use an adequate size of SB for compensating the shortage of inertia-less PV systems.

## IV. CONCLUSION

In case of spinning reserve technique the frequency fluctuates when there is a change in the production of, or in the demand for energy. If a generator trips, the frequency will decline. Depending on the prime mover and spinning reserve, the frequency will eventually go back to its desired value.Traditional load shedding scheme can't fit the new requirements of SPVG connected grid. Traditional load to be shed may exceed the actual power mismatch, to compensate the kinetic energy released by traditional synchronous generators.

In case of system frequency model, by using SBs and demand response the system frequency can always be kept within the desired range. The strategy managed to restore the system frequency in a short period and it never decreased bellow 49.83Hz.

From the above results we can concluded that the system frequency is stabilized to its previous value in less time in case of system frequency model rather than the proposed spinning reserve technique. The system frequency model takes less than 4 sec to stabilize the system frequency to its previous state, for which the whole system will never go under frequency condition.

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