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Study Committee C4

Power System Technical Performance

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Frequency Regulation for Low Inertia Power System with High Penetration of Photovoltaic System

Khaled Al-Maitah[1], Abdullah Al-Odienat[2]
[1]Electricity Distribution Company, Jordan
[2]Mu'tah University, Jordan

Abstract

The large integration of RESs and the replacement of conventional power plants with renewable energy sources (RESs) introduce challenges. For example, conventional power plants are replaced by wind turbines (WT) and photovoltaics (PV) power plants, which do not contribute to system's inertia. This large integration has led to a significant dynamic characteristic change in power system operation. As a result, power system inertia decreases, and frequency stability becomes a concern.

This study proposed a technique called 'de-loading' to increase the power system inertia and improve the frequency response of low inertia power system due to large integration of RESs. The proposed control strategy is modelled using MATLAB/Simulink. To investigate the performance of proposed method, the frequency response during large sudden disturbance is investigated with and without the de-loading technique. As a result, the proposed technique efficiently enhanced the frequency regulation by enabling the reserve power in PV power plans to mitigate the frequency deviation.

Inertia analysis in power systems

Power system frequency can be considered as an indicator that represents the balance between generation and load. The frequency response of single generator is highly affected by the inertia constant. Fig. 1 presents the graphical representation of a typical frequency response of the power system after any large disturbance. After any large disturbance, the initial response is determined by the system inertia Hsys. Where, the Initial ROCOF during system disturbance is inversely proportional to the inertia of the system Hsys.

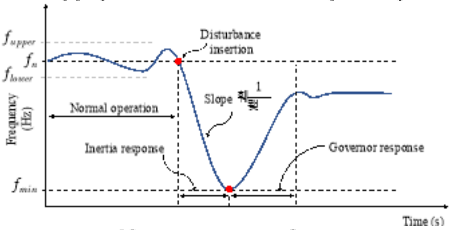

Fig.1. Typical frequency response of power system.

The dynamics of the motion of the generator's rotor can be described in a swing equation. Thus, The rate of change of frequency (ROCOF) can be written as:

$$\frac{df}{dt} = \frac{f_s}{2H_{sys}S_B}(P_m - P_e)$$

Fig.2 depicts the impact that different values of system inertia on the frequency response, the rate of change of frequency is inversely proportional to the system inertia H_{sys}. Where, the lower inertia, the higher ROCOF.

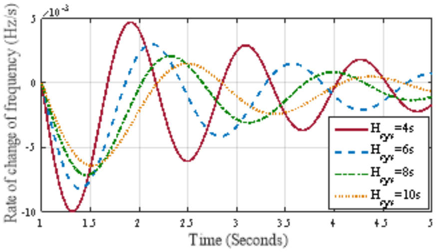

Fig.2. ROCOF for different values of inertia constant H.

Nowadays, the investment of PV sources is rapidly increasing. In Jordan, the penetration level of RES is about 20% and it is expected to reach 31% in 2030, this could adversely affect the system operation due to the reduction of system inertia. Moreover, when PV penetration becomes high, any small system unbalance is enough to trigger under-frequency load shedding (UFLS) relays.

The proposed control strategy

Conventionally, the PV power plants are operated in maximum power point tracking MPP mode to maximize the generated power of the PV power plant. As shown in Fig. 3, due to the continuously changing in temperature and irradiation during a day, the power system inertia is variating, also. the system inertia is critical during the peak time of PV power output between A and B in Fig. 3.

Traditionally, the PV power plant cannot participate in frequency response due to the lack of reserve power. Whereas, if the PV output power is restricted to be lower than MPP, during the peak period, a reserve energy will be produced.

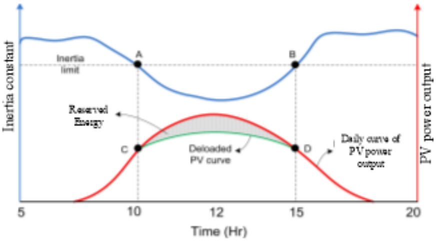

Fig.3. The variation of power system inertia due PV penetration level.

Frequency Regulation for Low Inertia Power System with High Penetration of Photovoltaic System

Thus, the proposed control strategy based on operating the PV power plants at a point lower than the optimum power point. For better understand the proposed method the P-V curve of the PV power plant is presented in Fig.4. As depicted in Fig.4, the operating voltage involves two different values, the first one located under the maximum power point voltage which is $V_{oper,1}$ and the second one located over the maximum power point voltage which is $V_{oper,2}$.

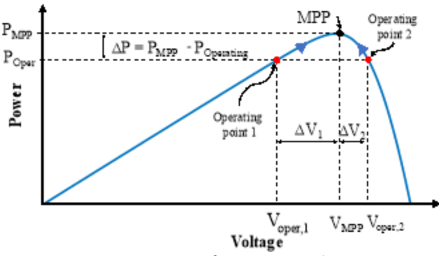

Fig.4. P-V curve for PV power plant.

In the proposed method the transition process from MPP to the new operation point based on the system inertia. Normally, the PV plant operates at the MPP, but when the system inertia falls below a certain level the operating point shifted to the point 1 or 2, this mechanism is called “De-loading”. In this study, the change in power system inertia is considered as factor to trigger the proposed mechanism.

Practically, a real time inertia estimation could be used as an input to trigger the proposed controller. Additionally, a control signal from the system operator could be used to trigger the proposed controller in case of low latency communication system.

Experimental setup

A typical power system has been considered to investigate the proposed control strategy. As in Fig.5, the system under study has two interconnected area, which are connected to each other through tie line. Where, each area consists of one conventional generation unit and one PV unit.

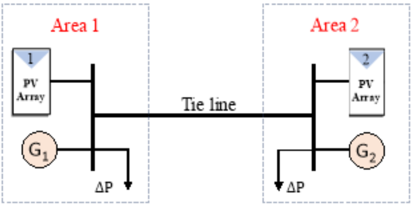

Fig.5. System under study.

For simulation purposes, the system has been linearized and modelled in MATLAB/Simulink environment with its frequency control loops as in Fig.6. Each area is represented by generator, governor and turbine model. However, to analyze the effective of the proposed control strategy, the frequency response of the of the two-area test system is obtained in two different scenarios.

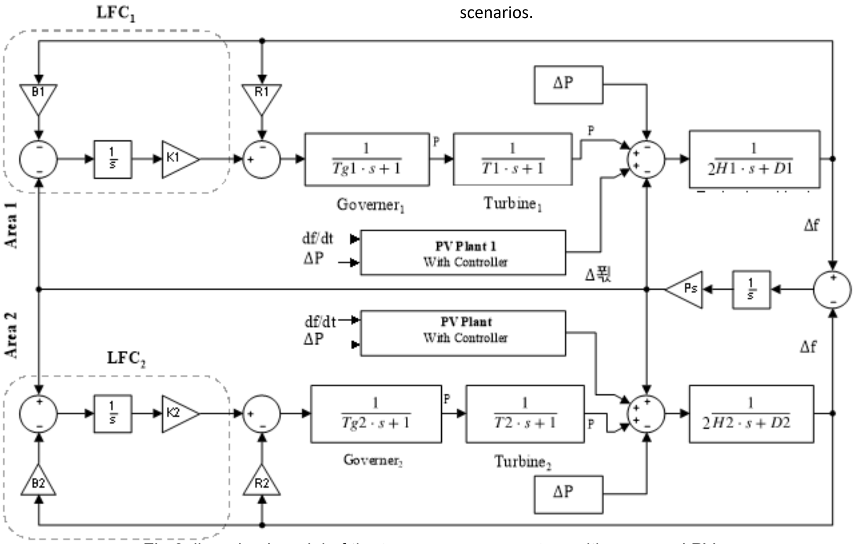

Fig.6. linearized model of the two-area power system with proposed PV control.

Study Committee C4
Power System Technical Performance
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Frequency Regulation for Low Inertia Power System with High Penetration of Photovoltaic System

Results and discussion

To analyze frequency response of the system a 0.2pu is applied as load disturbance in area 1 of the test system, which is represent as 200MVA load increasing. The frequency responses for area1 and area2 with de-loading technique and without are presented in Fig.6 and Fig.8, respectively. It is clearly shown, the frequency reached to unacceptable limit while the PV plant operating without proposed controller, that mean only conventional generator units are participated in frequency regulation and the PV plants are not activated in frequency regulation. Consequently, this may operate an unnecessary under frequency load shedding relay for a small disturbance or may cause blackout. by using the proposed de-loading technique, the PV plant become active in frequency regulation, where the frequency is regulated by both of conventional generator units and PV plants.

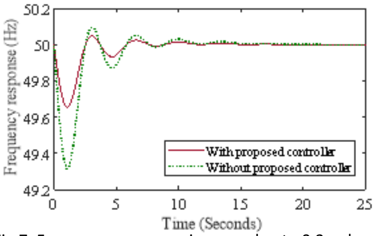

Fig.7. Frequency response in area$_1$ due to 0.2pu load change in area$_1$.

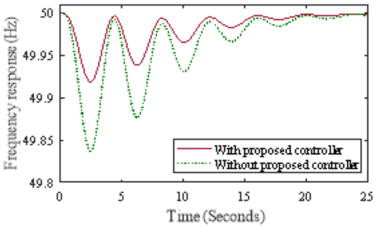

Fig.8. Frequency response in area$_2$ due to 0.2pu load change in area$_1$.

The change in output electrical power ΔP in generator 1 and 2, for both scenarios, are presented in Fig.9 and Fig.10, respectively. It is observed that, the ΔP in generator 1 in higher in scenario 1 (without proposed controller), that because there is no participated by PV plants to face the load disturbance. On the other hand, in scenario 2 the ΔP in generator 1 is decreased, that because the PV plant was operating at a point lower than MPP and its operating point was shifted toward the MPP when the ROCOF was increased due to the load disturbance.

Similarly, the participation of generator 2 in scenario 2 is lower than its participation in scenario 1. However, due the automatic generation control (AGC) loop, the participation of generator 1 is more the generator 2, that because the load disturbance was occurred in area 1.

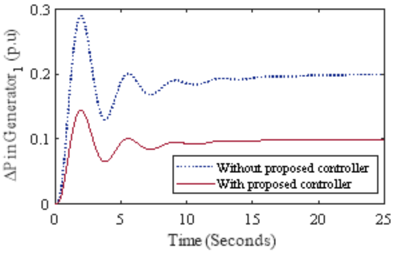

Fig.9. ΔP in generator 1 due to 0.2pu load change in area1

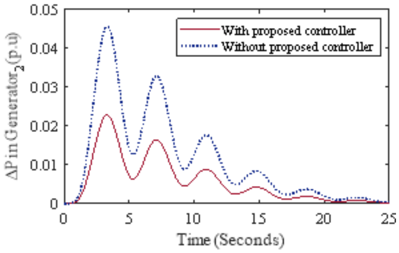

Fig.10. ΔP in generator 2 due to 0.2pu load change in area1.

Based on the previous results and since the time constant of inverter control system is very low compared with governor time constant, the PV plants by using the proposed controller can participate in frequency regulation. That by shifting the operating point to be lower than MPP while the system inertia is low. By this method, the PV plant can support the system by some reserve power.

Conclusion

This paper proposed a control strategy for grid-tie inverter to enhance the power system frequency regulation by the grid connected PV power plant. The proposed method can be concluded by forcing the PV plant to operate at a point lower than the maximum power point (MPP), while the system inertia is lower than the acceptable limits.

By using the proposed technique in the grid connected PV plants, an unnecessary of many blackout events, that may occur due to small disturbances, can be prevented. Consequently, the power system reliability and stability will be improved.