Active Power Priority Vs. Reactive Power Priority Operating Modes in Solar Plants

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SUMMARY

Penetration of renewable energy sources into the modern distribution and transmission power grid continues to increase around the world. Among the renewable energy sources, solar power generation is rising at a rapid pace due to a combination of government policies and economic factors. In particular, the cost associated with Photovoltaic (PV) installations continues to fall. Therefore, the characteristics of solar plant behaviour will have a growing impact on power system performance [1].

Solar cells are connected to the power grid using power electronic inverters which convert the DC output voltage of the solar cells to AC voltage. A solar inverter has a nominal apparent power rating beyond which the inverter should not operate. The inverter is capable of generating both active power and reactive power independent of each other as long as the apparent power is within the limit, i.e., below its rating. Once the apparent power reaches its limit, the inverter will determine to give priority to either generating active power or reactive power. These options are called active power operating mode (P-priority) and reactive power priority (Q-priority), respectively.

One option to operate a solar plant in the middle of a summer day is in such a way that the maximum active power is produced by the plant. In this situation, the reactive power consumption increases, and the voltage support provided through reactive power injection becomes essential for the network. Therefore, following a disturbance in the network, it is critical to determine whether to give the priority to providing active power or reactive power and support the network voltages.

Active power and reactive power variations during a disturbance can cause problems in the power system such as compromised voltage stability, frequency control issues, and operational forecast errors. There could also be issues if the solar plant is operating under the active power priority mode during and following instances such as cloud covering and contingency events.

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This paper aims to model and simulate a solar plant using both active power priority and reactive power priority operating modes. The results of both options will be thoroughly investigated and compared with each other and the advantages and disadvantages of each option will be explained. The investigations will be done by performing several tests such as frequency disturbances, disturbances caused by contingency events, and step responses. The tests will be performed for several network conditions including both weak networks with low short circuit ratio (SCR) at the point of interconnection (POI) and strong network with high SCR at the POI.

KEYWORDS

Renewable energy, Solar plant, Generator interconnection, Active power priority, Reactive power priority, WECC generic renewable models, Weak network.

1. INTRODUCTION

As the penetration of renewable energy sources increases, the impact of their dynamic model performance in stability studies becomes more critical. Each vendor usually provides a unique user model for stability studies which are conducted as part of the transmission system planning process. These user models can cause issues such as, dynamic case initialization errors and high frequency oscillations during single-phase fault application. Due to the lack of documentation and transparency into the inner workings of a user model, it is difficult for utilities and independent system operators (ISOs) to perform investigations. As a result, utilities and ISOs are moving towards using generic models. Organizations such as Western Electricity Coordinating Council (WECC), North American Electric Reliability Corporation (NERC), and Cigre highlighted the necessity of public standard models for variable generation technologies including wind and solar generations which was called generic models [2, 3].

A collaborative community of stakeholders including several commercial power system simulation software vendors, equipment manufacturers, utilities, two national laboratories (NREL and Sandia) worked under the WECC's Renewable Energy Modeling Task Force (REMTF) which resulted in development of the generic stability models for wind generators and photovoltaic generation as well as battery storage systems. The second generation of generic renewable energy systems models consists, at this time, of a library of ten models, i.e., REGC_A, REEC_A, REEC_B, REEC_C, REPC_A, WTGT_A, WTGAR_A, WTGPT_A, WTGTRQ_A and WT1P_B [4, 5].

2. DYNAMIC MODEL AND DISTURBANCE TESTS

In this section, a PV plant level model based on WECC generic modules is shown. Next, different tests on a PV plant model are discussed.

2.1. PV Plant Model

A PV plant model is shown in Fig. 1. As it shown, the model is composed of three different modules as follows [4]:

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a) *regc_a* – which is the renewable energy generator/converter model and has inputs of real (*Ipcmd*) and reactive (*Iqcmd*) current command and outputs of real (*Ip*) and reactive (*Iq*) current injection into the grid model.

b) *reec_b* – which is the renewable energy electrical controls model b, and has inputs of real power reference (*Pref*) that can be externally controlled, reactive power reference (*Qref*) that can be externally controlled and feedback of the reactive power generated (*Qgen*). The outputs of this model are the real (*Ipcmd*) and reactive (*Iqcmd*) current command.

c) *repc_a* – which is the power plant controller (PPC) model *a*. This model has inputs of either voltage reference (*Vref*) and measured/regulated voltage (*Vreg*) at the plant level, or reactive power reference (*Qref*) and measured (*Qgen*) at the plant level. The output of the *repc_a* model is a reactive power command that connects to *Qref* to the *reec_a* model.
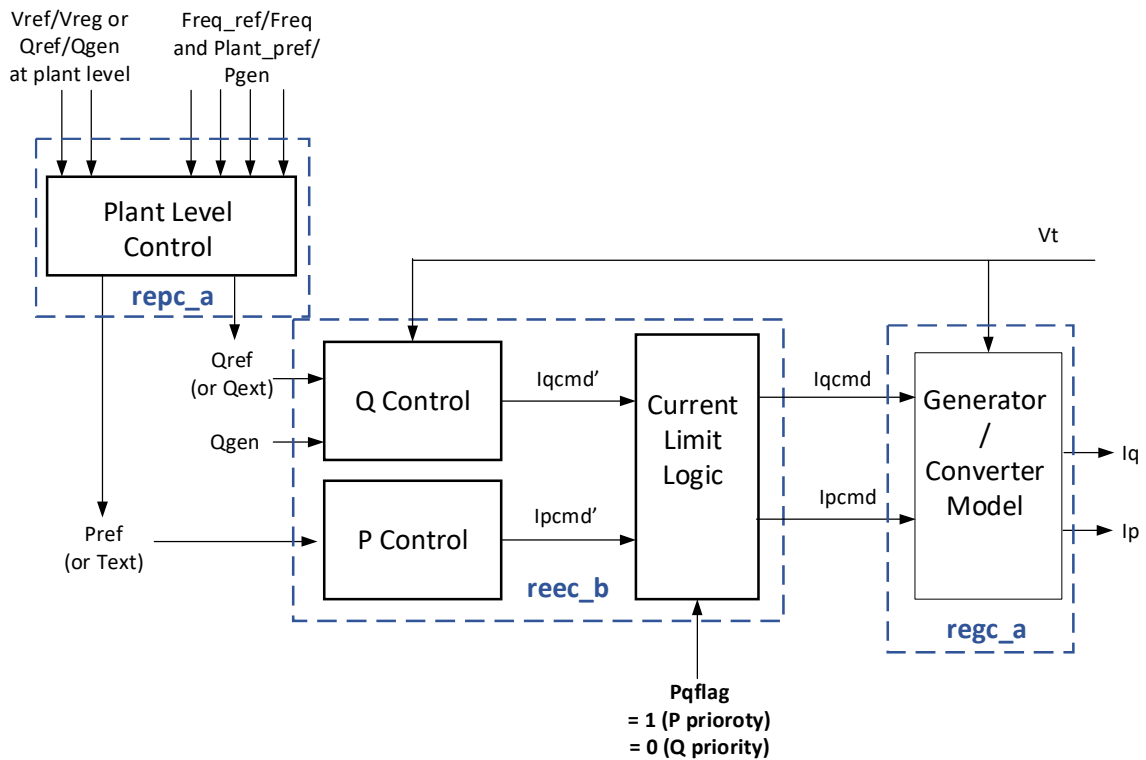

Fig. 1. Generic WECC PV plant model [4]

The focus of this study is to compare the response of the PV plant model in the P and Q priority modes in different tests. As shown in Fig. 1, this priority can be set in *reec_b* model using the *Pqflag*. Setting *Pqflag* parameter to 1 results in the P priority, while setting it to 0 results in P priority.

2.2.   Disturbance Scenarios

Each of the utilities and ISO's have different criteria for testing the model of a generator [6]. In this section, different tests are introduced that are used to compare the responses with P priority versus Q priority. The tests are as follows:

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a) *Generating unit response to fault event*: Fault ride-through performance of the generating unit was tested under three-phase fault at the POI for 9 cycles resulting in voltage profile of 0% at the POI.

b) *Voltage and reactive power control:* Voltage and reactive power control were tested under the +3% Voltage setpoint change applied in the PPC.

c) *Generating unit response to frequency disturbance*: Frequency ride-through performance of the generating unit was tested under the frequency disturbance of two percent, i.e., the frequency was increased from 60 to 61.2 Hz, i.e., +2% step change.

All of the above tests were conducted in weak and strong grid situations. i.e., high and low short-circuit ratio (SCR) values.

3. SIMULATION TEST AND RESULTS

A sample solar power plant was selected to simulate the tests in this paper. The power plant has a total active power capability of 101.5 MW, reactive power capability of ± 42.4 MVAr, and Mbase of 110 MVA. Considering the loss in generator step-up transformer (GSU), collector system equivalent, main transformer and the attachment line, the power plant will have a maximum facility output of 100 MW active power to the POI. The slider diagram of the model of the power plant in PSS®E is shown in Fig. 2.
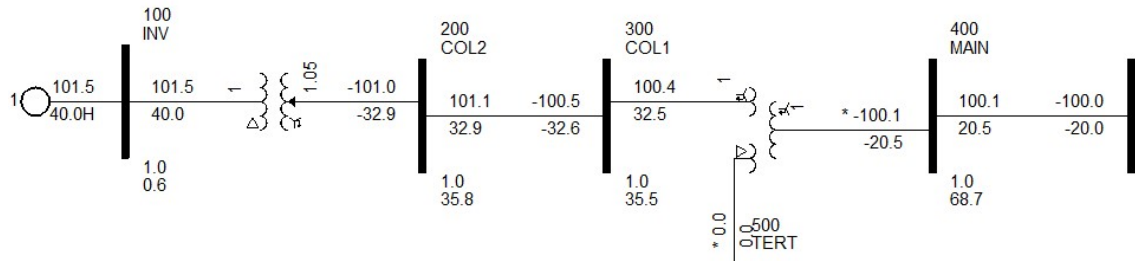

Fig. 2. Slider diagram of power plant model in PSS/E®

The dynamic model of the power plant has been set up to "Plant level V control" mode at the POI.

The Fig. 4 – 6 show the voltage magnitude, active power and reactive power at both POI and inverter terminal and frequency at POI for the three tests of fault event, voltage setpoint change and frequency disturbance.

Fig. 3 illustrates the test results for a three-phase fault at the POI with high SCR. In this test, both P-priority and Q-priority modes provide similar steady-state results. However, the voltage recovery profile is better for the Q-priority mode, while the active power recovery profile and frequency response of the system are better for the P-priority mode.

Fig. 4 shows the response of the plant for the three-phase fault with low SCR. It is clear that the response is not realistic at the POI when using the P-priority mode for a weak network as the system variables do not recover to their pre-fault values. However, the results are

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acceptable in Q-priority mode. This can be attributed to a faster reactive power support from the model during recovery leading to a better voltage profile.

It should be noted that the exact SCR value showing the boundary between a weak and strong network is not known and can be dependent on other factors such model parameters and network specifications. Therefore, it is possible that a model can still provide acceptable results using the P-priority mode for weak network by tuning parameters. Care should be taken when using the generic models operating in P-priority mode in weak networks because of vulnerable voltages.

Finally, Fig. 5 and Fig. 6 show the response of the system for the voltage and frequency step change tests. The results are the same for the P-priority and Q-priority modes. This is because the transients during these tests do not disturb the model in such a way as to make the model critically prioritize active power over the reactive power, or vice versa.
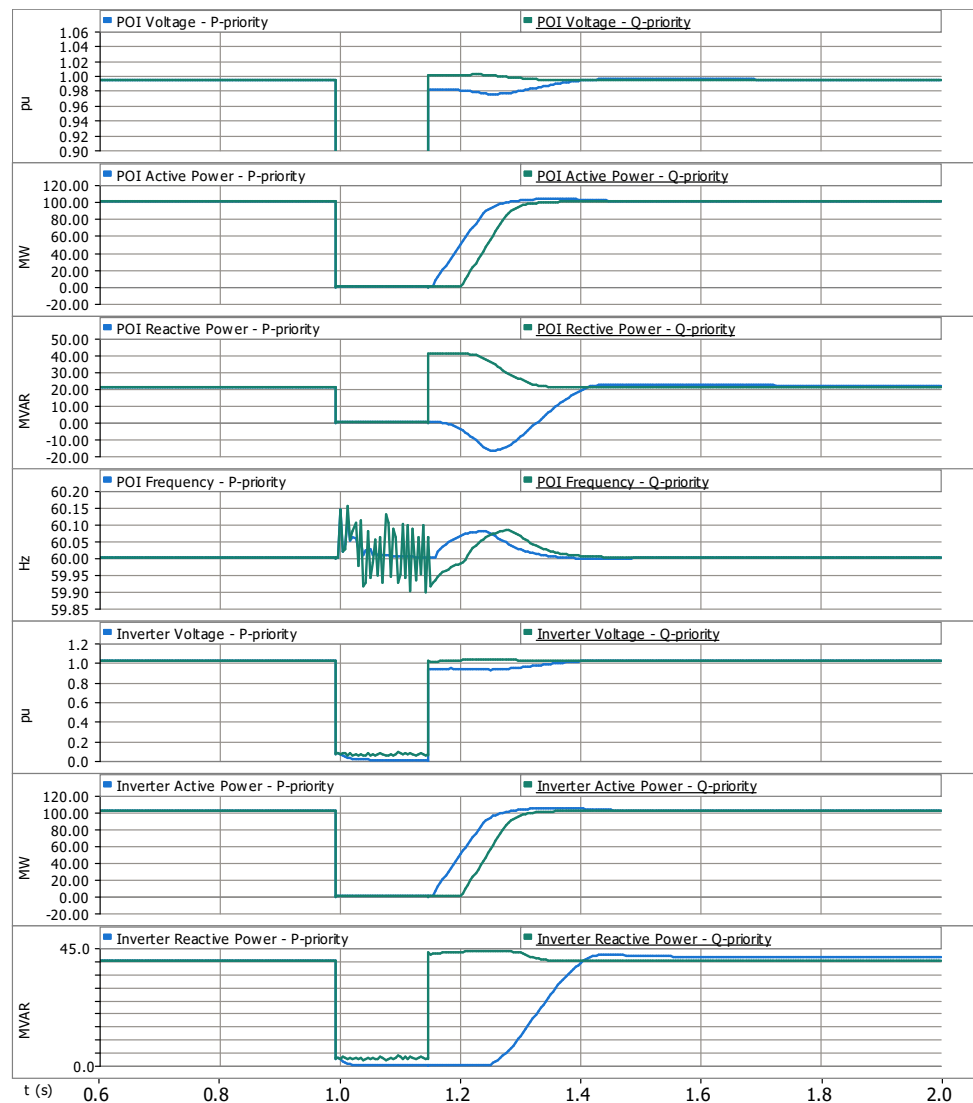

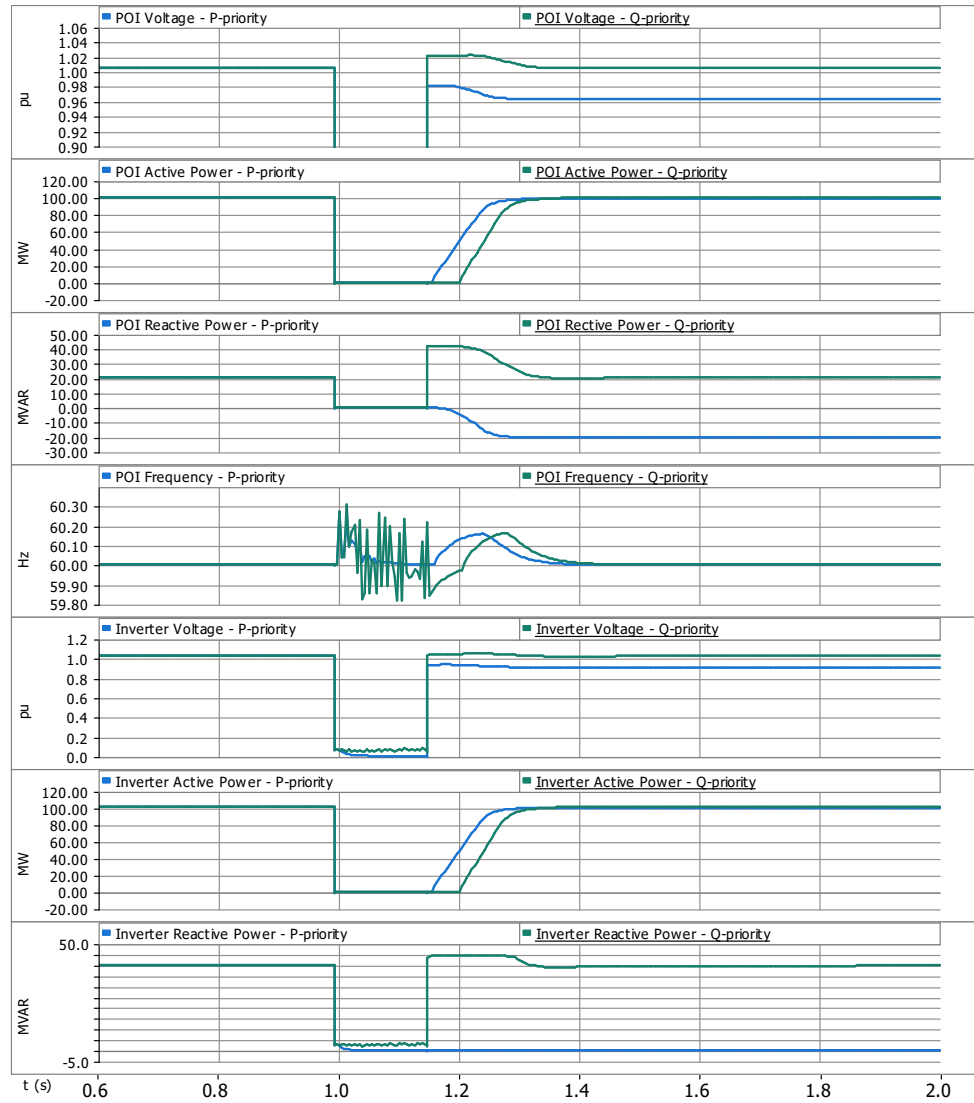Fig. 3. Results of the three-phase fault at POI for a strong network (high SCR)

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Fig. 4. Results of the three-phase fault at POI for a weak network (low SCR)

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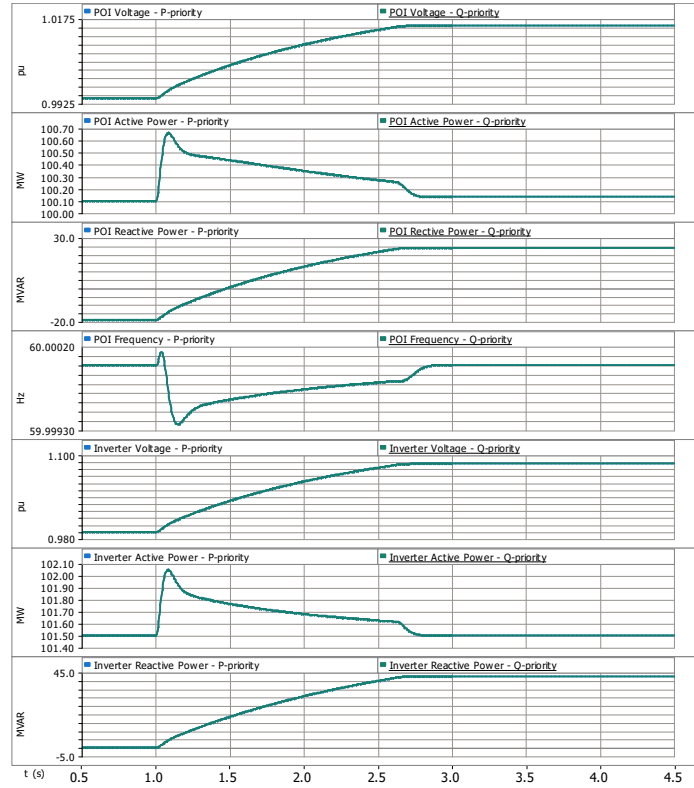
Fig. 5. Results of the voltage step change test
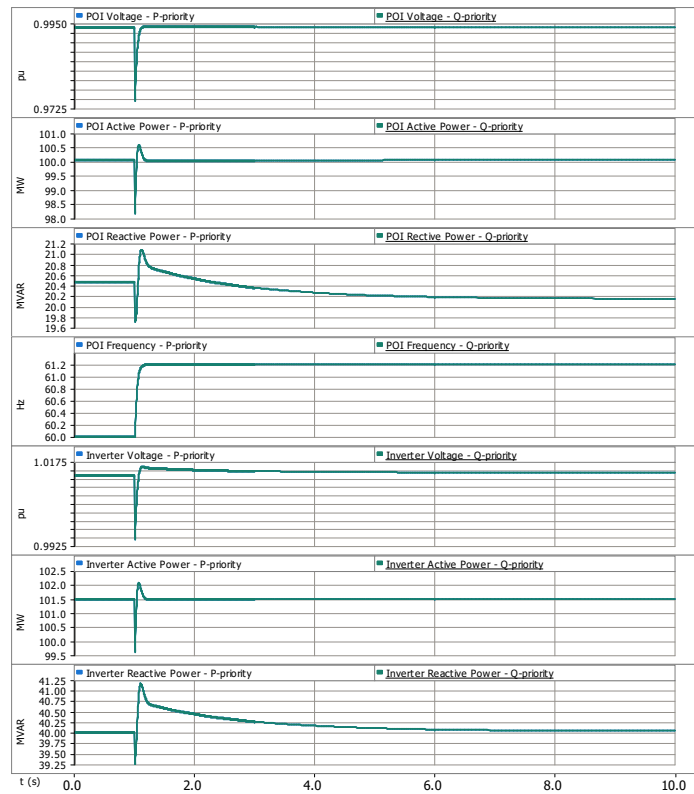
Fig. 6. Results of the frequency step change test

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4. CONCLUSION

In this paper the performance of a solar plant modelled using WECC generic models was investigated using both active power and reactive power priority modes. Three different tests were performed, i.e., fault event, voltage setpoint change and frequency disturbance. The results in the three-phase fault test show that under strong network conditions, P-priority mode leads to better active power and frequency recovery, while Q-priority mode gives better reactive power and voltage support. If the SCR of the system is decreased, the results are prone to be unrealistic in P-priority mode. However, in Q-priority mode, the results are more reliable since faster reactive support is provided by the model resulting in improved voltage profile. Care should be taken when using the WECC generic models in a network with low SCR values in P-priority mode.

Finally, the two tests of voltage setpoint change and frequency disturbance did not show any difference in P- versus Q-priority modes since the model was not disturbed to a limit to prioritize active power over reactive power or vice versa.

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