DISTRIBUTED GENERATOR CONTROL MODE AND ITS EFFECT ON THE DYNAMIC BEHAVIOUR OF A DISTRIBUTION NETWORK

A synchronous distributed generator (DG) power generation is controlled at specific modes, defined as Voltage control mode (PV) and power factor control mode (PQ), to demonstrate an electrical network dynamic behaviour as a result of DG connection to the system. PSCAD/EMTDC software is used to model and simulate the network. The results show the network profiles correspond to the different amounts of DG power generated.

INTRODUCTION

Studies on generator controls have found that it is possible to equip a DG with flexible mode/s of operation [1]-[2] so that the DG can operate in any mode whenever the network demands it. However, these features are too complex for SSDG. Another study [3] suggests that connecting a DG that conforms to unity power factor to a distribution system will face threats from harmonics. Many types of controls for power generations for SSDG are being designed and analyzed [4]-[6]. Some of these control features enable the generators to operate in power factor control mode and voltage control mode. However the impact of integrating SSDG with these operation modes has yet to be further analyzed.

The drive for exploring distributed generation in Malaysia is due to its having unlimited renewable energy sources and its pledge to support the Kyoto Protocol. The increase in petroleum oil price also indicates a warning for all so as to seriously considering many other alternatives for energy sources applications. Furthermore, DG placement in a distribution system is not planned beforehand because industries and the IPP, who owns the EG, would rather have a DG installed locally. Domestic DG will also be installed close to home. This way, installed DG might not be strategically placed and thus once installed; it exhibits stability and reliability issues.

Among the reasons for this paper to explore DG control modes and their impacts on a distribution network power flows are due to the issues arises from the uncertainties in requirements and connection specifications for the DG connection to the distribution system with regards to the following aspects [7]:

a) The specifics of load level of the distribution system to allow for base load generation are not available;
b) The requirements for a DG to adopt voltage control are not clear and may also be over-specified;
c) The contributions of the DG penetration level towards the reduction or the increase in losses are not addressed;
d) The requirements for system and detail design studies seem to vary from project to project; and
e) The options for the interface design between the DG and distribution system are not provided and exhaustive.

PV mode refers to sustaining DG real power (MW) generation at a constant value. The DG responses to the AVR by either generating reactive power (MVAr) to or absorbing reactive power from the distribution network in order to maintain the terminal voltage at a specified value. The minimum and maximum MVAr has to be specified in order to operate at a power factor between 0.9 leading and 0.85 lagging, else the plant operators will be charged for operating at "bad" power factor (p.f.) [8]. PQ mode refers to the DG generation of a fixed MW and a fixed MVAr. In this mode, the power output of the generating unit is maintained at selected values of MW and MVAr which defines the power factor regardless of the DG terminal voltage. Voltage profile varies as the distributed generator’s power generation reduces or increases. This variation will be illustrated by the distributed power generation modes, namely the PQ and PV modes. Studies on individual DG placement as in [3] provide some merit to this paper’s contents but it concerned minimum system loss on a test system. In contrast, this paper focuses on the behavioral characteristics of a selected Malaysian distribution network due to individual influence from a synchronous generator with varied mix of MW and MVAr generation levels that corresponds to each DG operation mode.

This paper intends to explore the effects a DG generation modes have on power flows and network profiles of an electrical power distribution system by using PSCAD/EMTDC power simulation software on a selected Malaysian distribution network. The simulation result indicates the DG generation in PQ mode, at any DG generation levels, causing distinctive oscillation thus resulting in network voltage fluctuation. These results trigger an appreciation towards the oscillatory behavior of the distribution system when DG is set at PQ control mode. This presentation suggests more simulations and system analysis should be carried out to aid and enhance understanding the behavior of an electrical network when a DG is inserted in an electrical power distribution system. This study hopes to provide basis and information for further research in the fields of Distributed Generation and Power System Planning. The details and explanation presented in this paper are able to provide a better insight on the electrical power distribution network responses towards the application of the DG control modes.

BACKGROUND RESEARCH

DG in Malaysia operates in power factor control mode. Power factor control refers to a fixed amount of real power and a fixed amount of reactive power generated from an EG. The DG p.f. is set to operate at 0.9 so as not to upset the grid point supply p.f. In this paper, the power factor
control mode is referred to as the PQ mode. Whenever the DG real power generation is varied, the reactive power will also be varied at a fixed ratio and at a set p.f. value. Voltage control refers to the installation of additional equipment, such as the AVR and OLTC transformer, which have to accompany the connection of DG in order to regulate a bus voltage at a specified value. Voltage is regulated by sourcing a fixed amount of real power and a varying amount of reactive power for compensation. Only large generators (>100MW) is equipped with voltage control. In this paper, voltage control mode or PV mode refers to a DG that can source only a fixed amount of real power while the DG terminal voltage is set at a specified value by means of generator excitation system. Initial study on an electrical network system showed that an increase in a bus voltage magnitude depends on the type of DG control modes [9]. Figure 1 shows a comparison of bus voltages with DG interconnected at ratings increases from 2MVA up to 10MVA. Fig 1 (a) represents the bus voltage at DG point of connection (PoC), and Fig 1 (b) represents voltage for a bus located further from PoC.

![Figure 1: Relationship between Bus Voltage and DG Ratings at different DG Control Modes](image)

The results show that the PQ control mode contributes more to the increase in the steady state bus voltage as the system stabilizes. Figure 2 shows the relationship between the generated DG MW and MVAr with respect to field voltage and applied torque. Figure 2 (a) indicates that an increase in the applied torque, while keeping the field voltage constant, changes the amount of MW generation. In Figure 2 (b), the MW and MVAr generated increase linearly with the field voltage while the applied torque is held constant. Thus, the DG p.f. is kept constant when this mode of control is used. This result indicates that the generator field voltage controls the MVAr generation while the applied torque controls the MW generation.

In this paper, simulation results were obtained using PSCAD/EMTDC software on a selected distribution network in Malaysia. The DG is a 10MVA synchronous generator and it is modelled based on the manufacturer’s data. The static load model selected is constant power model which represents the least severe impact on bus voltage variation [10]. The local load served by the DG measures at 1.3MW and the load power factor is 0.85. Several simulations using PV and PQ control modes were carried out to investigate their effects on the distribution network dynamics.

![Figure 2: The Effects of Applied Torque and Field Voltage on DG Power Generation](image)

**SIMULATION RESULTS**

The amounts of active and reactive power generated into the distribution network are based on its operating control mode. Using reactive-power-feedback feature in PSCAD, the DG field voltage and applied torque are varied in order to obtain their relationship between the DG MVAr and MW generation. The DG is inserted into the network at 5-kV bus, after the network converges to its steady-state condition, and it is controlled manually to operate in PV mode or PQ mode. Simulations in PSCAD/EMTDC are performed corresponding to the following matrix:

- a) In PV mode; The DG power generation is increased from 0.5MW to 2.0MW in steps of 0.5MW while the PoC voltage is set at levels 0.98 and 0.96p.u.
- b) In PQ mode; The DG power generation is increased from 0.5MW to 2.0MW in steps of 0.5MW while the p.f. is set at 0.7 leading and 0.9 leading.

For all simulations, graphs are presented to show the power flows in/out of PoC and the voltage profiles at PoC corresponding to PQ and PV modes of DG operation.

**A. Network Active Power Flows Due to the DG Control Modes**

The profile shapes of Figure 3(a) and (b) show active power flowing from the grid supply into the point of common connection (pocc) for PV control mode when PoC is controlled at 0.98p.u. and 0.96p.u. respectively. The transient behaviour refers to the DG energizing stage where the DG active power generation increases at the application of the driving torque resulting in excessive reverse power flow at pocc.
Figure 3: The Active Power Flows into PoC from the Grid due to PV Mode when PoC is controlled at (a) 0.98p.u. and (b) 0.96p.u.

Figure 4 refers to active power flow profiles corresponding to PQ control mode. The transient portion indicates that the grid supplies more power for the DG to energize. However, the DG function as a generator is altered at 2.0MW DG power generation setting. The profile suggests the DG behave as a motor.

In both Figure 3 and Figure 4, the system adjusts at steady-state in order to accommodate for the local active power demand. Since local load is only 1.3MW, the grid power is flowing negative as indicated by the profiles corresponding to DG power generations of 1.5MW and 2.0MW. This result suggests that DG manipulates the local load active power supply.

B. Network Reactive Power Flows Due to the DG Control Modes

Figures 5 and 6 show the grid supply power flows corresponding to PV control mode and PQ control mode respectively. Both figures indicate the DG draws an amount of reactive power from the grid to build up flux linkages in order to produce back e.m.f. and accelerates. The larger the amount of DG power generation, the larger the reactive power is drawn from the grid supply.

Referring to Figure 5 (a), the DG is supplying all the local load reactive power at 0.98p.u. while the grid supplies the same at 0.96p.u. setting as seen in Figure 5 (b). Figure 6 shows that the grid reduces its local reactive power supply as the PQ mode DG power increases.

C. Network Voltage Variations Due to the DG Control Modes

Figure 7(a) indicates an insufficient power generated by the DG to maintain the PoC voltage at 0.98p.u. At this setting, the DG can only raise the PoC voltage up to 0.97p.u. as indicated by the steady-state PoC voltage shown. Figure 7(a) shows that 0.96p.u. control level is achieved as the DG generates excess reactive power into pocc.

Voltage profiles at PoC for the PQ mode settings can be observed in Figure 8.

Figure 4: The Active Power Flows into PoC from the Grid due to PQ Mode when DG p.f. is at (a) 0.9 and (b) 0.7 lagging.

It is conclusive that reactive power oscillation as in Figure 6 introduces voltage oscillation at PoC and the maximum amplitude of oscillation corresponds to the leading PQ p.f. 0.7 setting as shown in Figure 8(b). The network steady-state profile shows that the DG supports local reactive power demand at lower lagging p.f. setting. It is also can be deduced from Figure 8 (b) that the steady-state voltage will rise as the DG active power generation is increased at PQ control mode. The grid reactive power is foreseen to oscillate vigorously thus introduces instability to the system.

CONCLUSION

The following can be concluded from this study:
1. DG penetration level is limited in PQ control mode;
2. DG priority is to supply local active load, in both control modes as long as its generation is within the penetration level limit;
3. DG supports partial local reactive load at PQ control mode settings. Higher amount of reactive power is supplied at lower p.f. setting;
4. DG priority to supply local reactive load when operating in PV control mode;
5. PQ control mode causes reactive power flow to oscillate;
6. PQ control mode causes network voltage to oscillate;
7. Network voltage sags at transient if PQ control mode power generation is larger than local active load;
8. PV control mode results in more damped reactive power flow profile.

Figure 6: The Reactive Power Flows into PoC from the Grid due to PQ Mode when DG p.f. is at (a) 0.9 and (b) 0.7 lagging.

Figure 7: The PoC Voltage Profiles due to PV Mode when PoC is controlled at (a) 0.98p.u. and (b) 0.96p.u.

Figure 8: The PoC Voltage Profiles due to PQ Mode when DG p.f. is at (a) 0.9 and (b) 0.7 lagging.

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REFERENCES

BIOGRAPHIES

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