

DISTRIBUTED GENERATION: BENEFITS AND CHALLENGES

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Abstract— Distributed Generation units are anticipated to penetrate the distribution system within the next decade. Despite the many benefits a DG can provide, there are still a lot of challenges that need to be addressed in order to fully deploy DG into the system. One of these challenges is islanding protection. Before a DG can be connected to the distribution system, it must be tested for islanded operation. The paper highlights the benefits of installing distributed generation in the distribution system and focuses on islanding operation. Simulation results describing the performance of different inverter-based DG interfacing on islanding detection are presented. It is concluded that islanding might not be possible to detect in some operational scenarios.

Keywords: distributed generation, dynamic model, islanding detection methods, nondeceptive zones

I. INTRODUCTION

Reliable, efficient, low-cost and high-quality electricity supply is one of the major factors for improving and maintaining a high standard of living. The key requirements in an optimized electricity system are supply security, improved system efficiency, high system reliability, affordable energy cost, improved system power quality, low environmental impact and the effective integration of available sustainable energy resources. Currently, the electricity supply faces significant challenges from different avenues such as environmental pollution, decline of our indigenous energy supplies and the need to update our energy infrastructure. Although it is generally accepted that centralized electric power plants will remain the major source of electric power supply for the future, it is evident that simply stringing together more central plants and wires will lead to a more fragile and vulnerable power system.

Recently, the deregulation of the electricity market has opened a new and attractive opportunity for decentralized energy resources to play a significant role in optimizing the performance of the overall electricity system. Adding decentralized technologies, known as Distributed Generation (DG) can manage electricity demand and generate clean on-site power that will increase the reliability of the system, increase the price elasticity of

demand for centralized power and reduce system losses. Moreover, since most DG technologies are sustainable; such as wind, photovoltaic, geothermal or hydroelectric, or

clean energy sources such as fuel cells, cogeneration or biomass, significant environmental benefit can be achieved. Increased deployment of DG technologies will have a beneficial impact on the government's energy policy goals, which are to reduce emissions, ensure a reliable energy supply, and to promote competitive markets [1,2]. Moreover, DG brings additional attractive features to the utility system such as system security by diversifying the energy sources, improved power quality by injecting controllable reactive power, supplementary economical benefits by providing ancillary services, cost saving by reducing peak demand for central station power and remote power applications to defer new transmission installation [3,4]. Many of the DG technologies and systems required to make this vision a reality already exist while others are in the process of being developed. However, we need to ensure that we have a clear picture of the barriers currently preventing widespread take up and a substantial evidence base that allows us to identify the most cost effective measures to help sustainable and clean DG technologies make their contribution to our energy system. The integration of DG and storage devices into the utility grid will alter the contemporary practice of having a unidirectional power flow and will create highly dynamic interactions between system components; therefore, more advanced interfacing schemes will be required in order to ensure that the energy system component technologies work together seamlessly and effectively.

Islanding is a condition in which a portion of the utility system that contains both load and generation is isolated from the main utility system. Islanding detection methods can be divided into two main groups: passive and active methods. In passive methods, the decision whether an islanding condition occurred or not is based on measuring a certain system parameter and comparing it with a predetermined threshold. In active methods, DG voltage or frequency is forced to be unstable during an islanding situation.

II. DISTRIBUTED GENERATION BENEFITS

Distributed generation sources provide good flexibility and adaptation to the changes in the economical environment due to their short construction lead time and small size. Moreover, distributed generation technologies can help suppliers to fill in the slots in the liberalized market and provide electricity services as required by the customers. DG can provide several different benefits to the distribution system; some are listed below.

Peak Power Shaving

Distributed generation operation during peak demand periods (Peak Shaving) contribute in supplying demand power during these high demand periods and avoid problems that might be associated with high demands such as load shedding and transmission line congestion. In this way, distributed generation contributes in avoiding electricity price fluctuations and provides a flexible reaction in evaluating electricity prices. This is considered the major driver for distributed generation installation in US.

Power Quality Enhancement

Distributed generation can assist in solving power quality problems, such as voltage sags, as the installation of a DG increase the voltage level in the network. Moreover, distributed generation can also contribute in the power factor correction.

Network Reliability

Network reliability is considered the second major driver for installing distributed generation in US. Reliability of the power supply is a very important issue for industrial customers that may direct their investments in installing local distributed generation facilities to increase their reliability levels. Two technologies have been specifically identified by the IEA (2002) [5] to contribute in the prevention of power supply interruption.

- Combined backup system with an UPS unit.
- Fuel Cells

Moreover, for start-up time covering, combined gas-and-diesel engine with flywheels systems have been commercially available.

Expansion (or Local Network Use) Alternatives

Distributed generation substitutes or bypasses the costs for transmission and distribution systems expansions. However, increasing distributed generation units installations can contribute to the associated generation requirement problems such as increasing fuel transportation costs. It has been recorded that about 30 % savings in electricity costs can results from on site generation [6]. Distributed generators can operate in stand alone mode thus provide an alternative to connecting customers to grid. This can result in about 6.8 % reduction in grid losses and 10 – 15 % saving in network costs [4, 5].

Grid Support

Distributed Generation contributes in limiting and / or preventing the installation of auxiliary services to provide a stable and sustained grid operation without contributing

in supplying customers. An example of such services is the installation of external devices (voltage regulators) to regulate network voltages during disturbances. Inverter-based distributed generations can provide this functionality despite of the operating conditions.

Efficient Use of Cheap Fuel

Installing distributed generation units increase opportunity of using cheap fuels, e.g. burning landfill gases when distributed generation facilities are installed near landfills. In addition, they allow for utilizing costless fuels such as wind, water, and solar for renewable-based distributed generation.

Combined Heat and Electricity Generation

Using Combined Heat and Power (CHP) units allow cogeneration of heat and electricity. This is very effective, especially at locations where there is a continuous heat demand, rather than generating heat separately and obtaining power from the grid. CHP units increase the energy conservation by 10 – 30 % depending on the unit's efficiency and rating. For example, microturbines have very low efficiency (25 – 30 %) when used for electricity generation only. This efficiency is increased to about 60 % when used as a CFP unit.

Distributed Generation Main Advantages

Distributed generation units have many advantages that can be summarized as follows:

- ◆ Reduces dependence on major power plants. This results in eliminating the need to erect new big power generation and deferral of new capacity
- ◆ Reduces dependence on long-distance national transmission grid (releasing transmission lines capacities). This reduces cost of installing new transmission lines and reduces transmission congestion.
- ◆ Reduces transmission and distribution line losses.
- ◆ Reduces environmental impacts and greenhouse-gas emissions. This is because lots of DG units are renewable or low emission generators based sources.
- ◆ Reduces price volatility in energy markets.
- ◆ Enhances or preserve system reliability by having a back-up generation.
- ◆ Deferral of new capacity (postpone upgrading the T&D infrastructure).
- ◆ Enhances flexibility for system operators.
- ◆ Accelerates retirement of old units.
- ◆ Increases energy security by diversifying energy sources and reducing dependence on complex large systems.
- ◆ Increases personal, business and regional self-sufficiency.
- ◆ Well adapted to alternative and renewable energy sources.

III. DG INTERCONNECTION REGULATIONS

The IEEE Std. 929 and IEEE Std. 1547 both mandate the disconnection of the DG once it is islanded [7], [8]. This is mainly to avoid any power quality problems or

protection problems that would arise from such islanded situation. In literature islanding detection methods could be classified into two main groups: active and passive methods. In addition to islanding detection, the standard also requires the DG to operate close to unity power factor and the harmonics within the system should be within acceptable standard levels.

IV. DG ISLANDING DETECTION

For DG systems producing a DC voltage, an inverter is used to interface the DG system with the grid. The switching of the inverter is determined based on a certain implemented control strategy. The DG could be designed to supply active power or both active and reactive power. Aside from controlling the DG output power, the DG interface control performs an additional function, which is anti-islanding protection. A DG is islanded when it supplies power to some loads while the main utility source is disconnected.

Islanding Detection Methods

Anti-islanding detection methods can be divided into two main groups: passive and active methods. In passive methods, the decision whether an islanding condition occurred or not is based on measuring a certain system parameter (voltage, frequency, THD, and power) and comparing it with a predetermined threshold. Active methods, on the other hand, are designed to force the DG to be unstable during an islanding situation. In active methods, the DG voltage or frequency is forced to deviate from their nominal values (60 Hz or 1 pu) by providing a positive feedback. For islanding state, the inverter will respond to the deviation by drifting its voltage or frequency (based on the connected load). However, if there is no island, the utility will force the inverter to work at 60 Hz and rated voltage and the inverter will not follow the deviation.

Most of the developed islanding detection methods focused on DGs that operate at unity power factor. Recently, much work has been focusing on the DG interface to the grid and its operation and control.

Nondetective Zones

One of the important characteristics to determine the effectiveness of an islanding detection method is the Non-Detective Zones (NDZ). NDZ is the operating region where islanding conditions cannot be detected in a timely manner. It can be represented either in terms of power mismatch or in terms of the R, L, and C of the load. According to the IEEE Std. 1547 standard, the threshold for the voltage is 88% and 110% of the nominal voltage and for frequency; thresholds are 59.3 Hz and 60.5 Hz. This will be used in determining the NDZ.

V. SIMULATION RESULTS

In this paper, several interface controls for DGs are presented and their performance is studied during an islanding situation. Islanding detection in this paper is only based on Over/Under Voltage and Over/Under

frequency (OVP/UVF and OFP/UFV). The impact of DG interface control on the NDZ of OVP/UVF and OFP/UFV is also analyzed.

DG systems are connected to the distribution system through an inverter as shown in Fig. 1. The inverter performs two main functions:

1. Controlling the active power output of the DG and in some cases, injecting a suitable amount of reactive power to mitigate a power quality problem.
2. According to the IEEE Std. 1547, the DG should be equipped with an anti-islanding detection algorithm, which could be performed using the inverter interface control (active methods).

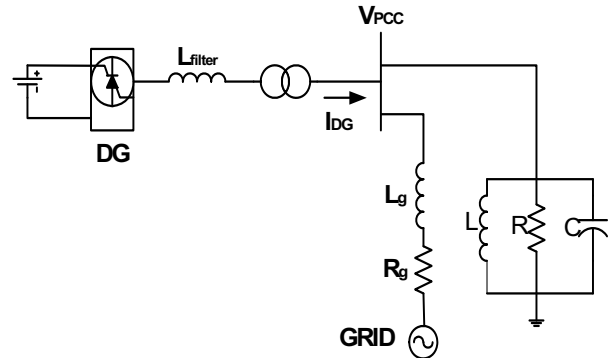


Fig. 1: A single line diagram of the system under study consisting of a DG, Grid and RLC load

The system under study consists of a 100 kW inverter based DG connected to an RLC load having a quality factor of 1.8 and a grid as illustrated in Fig. 1. The filter inductance is dependent on the maximum switching frequency and the inverter DC voltage. The performance of the DG under normal and islanded operating conditions was studied and simulated on PSCAD/EMTDC. The real load power was adjusted to place the inverter at 25%, 50%, 100%, and 125 % of the inverter's rated output. The reactive power was adjusted between 95% and 105% of the balanced condition (unity power factor loading) in 1% steps. For brevity, the following four loading conditions are presented:

Case 1: Load is adjusted to operate the inverter at 100% of its rated active power output and 100% reactive power balance.

Case 2: Load is adjusted to operate the inverter at 50% of its rated active power output and 100% reactive power balance.

Case 3: Load is adjusted to operate the inverter at 100% of its rated active power output and 101% of the reactive power balance condition.

Case 4: Load is adjusted to operate the inverter at 125% of its rated active power output and 95% of the reactive power balance condition.

Three different control strategies are going to be studied. The first is the constant current control interface where the DG interface control is designed to supply constant current output. The second control algorithm is the constant P-V control which provides voltage support by injecting reactive power at the Point of Common Coupling (PCC). The third is the constant P-Q control where the active and reactive powers are controlled to a

preset value. To examine the performance of the DG under islanding conditions, the grid was disconnected at $t = 3$ seconds. Figures 2 to 7 represent the frequency and the voltage at the PCC for the three control techniques.

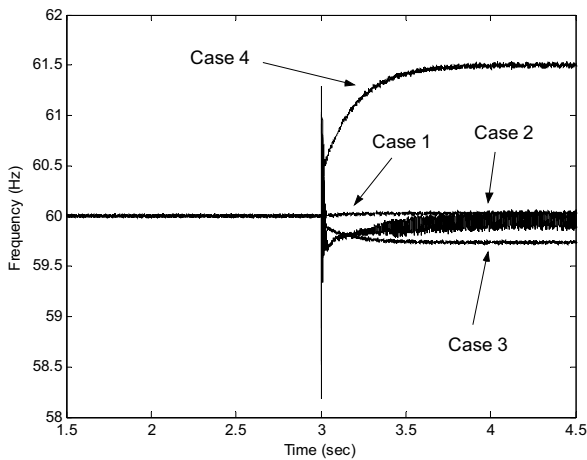


Fig. 2: Frequency at the PCC (constant current control)

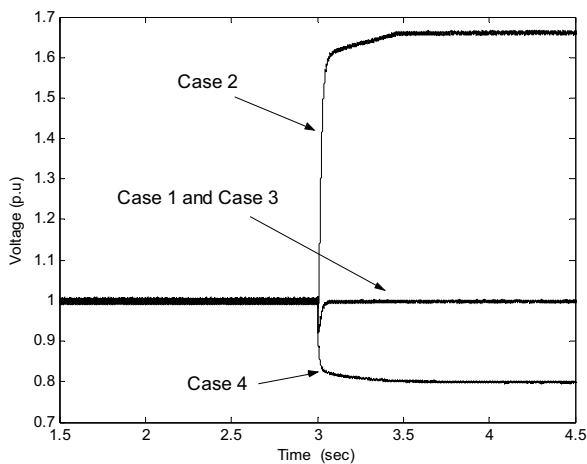


Fig. 3: Voltage at the PCC (constant current control)

Based on the simulation results, there are cases (Case 2 and Case 4) where the OVP/UVF and OFP/UFV will be capable of detecting islanding and others (Case 1 and Case 3) where it would fail.

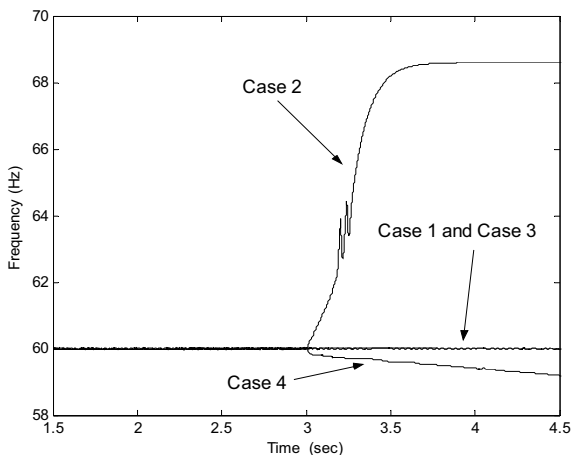


Fig. 4: Frequency at the PCC (P-V control)

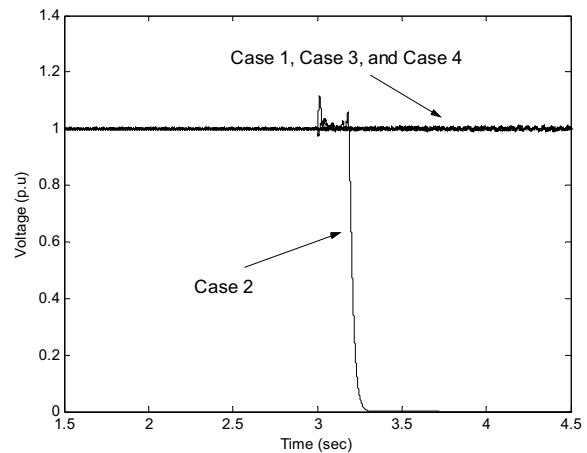


Fig. 5: Voltage at the PCC (P-V control)

It can be seen that the performance of the P-V interface is different from the constant current. Based on the simulation results, for both cases 1 and 3, both the voltage and frequency remain within their standard permissible levels after islanding occurrence and islanding will not be detected. This is as a result of the balance between the load and rated DG active power output. Although the load absorbs reactive power (Case 3), the frequency remains at approximately 60 Hz after the DG is islanded due to the capability of this interface of supplying reactive power. For the remaining two cases (Case 2 and Case 4), due to the active power mismatch, the DG becomes unstable and the frequency deviates, thus islanding could be detected using the OVP/UVF and OFP/UFV.

For the P-Q control, the voltage level at the PCC is affected by the active power mismatch while the frequency at the PCC is affected by the reactive power mismatch. It can be seen that the value of the PCC voltage is dependent on the island load active power. If the amount of power mismatch is not large enough, the deviation in PCC voltage will not be sufficient to trigger the OVP/UVF. Similarly, for a DG operating at unity power factor, if the load on the island absorbs reactive power, the frequency at the PCC will deviate in order to satisfy the unity power factor operation of the DG. For this interface, both the active and reactive power output of the DG remain fixed, even after islanding occurrence. From the simulation results, the OVP/UVF and OFP/UFV can detect islanding for cases 2 and 4 and will fail to detect for cases 1 and 3 [9].

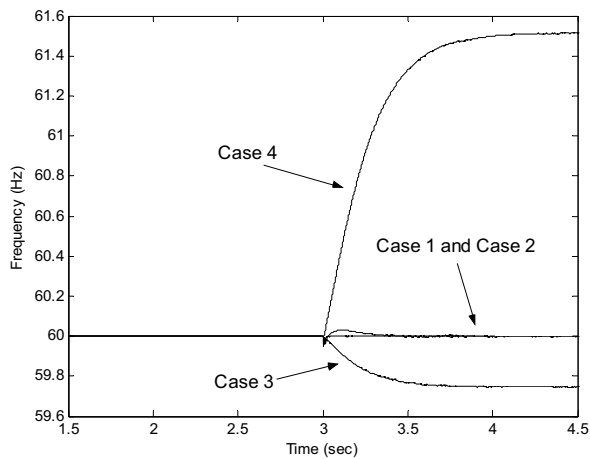


Fig. 6: Frequency at the PCC (P-Q control)

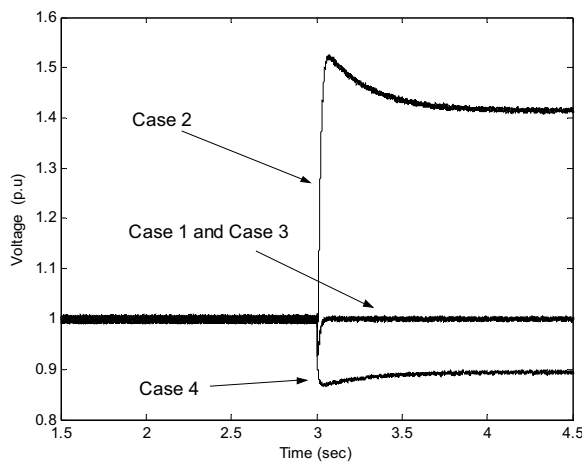


Fig.7: Voltage at the PCC (P-Q control)

VI. CONCLUSIONS

The interconnection of DG to the distribution system can provide many benefits such as peak shaving, power quality enhancement, grid support and efficient use of cheap fuel. One of the challenges associated with DG operation is islanding. The interface control is an important factor that should be taken into consideration when designing the islanding detection method. The operation of the DG during an islanded situation will differ based on the interface control. This issue should be taken into consideration in future standard revisions.

VII. REFERENCES

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