USING DG FOR ANCILLARY SERVICE AND SECURE OPERATION OF POWER SYSTEM

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ABSTRACT

This paper gives some general discussions how to use small generators or distributed generation (DG) to provide ancillary services. DG is not only playing an important role in power generation, but also can be a source providing ancillary services. Due to the local connection and near consumers, the contribution of DG is significant with local control variables such as voltage regulation or power loss reduction.

INTRODUCTION

Generally, ancillary services of a power system have been provided and guaranteed by large synchronous conventional generators, normally connected to the transmission system. This is done by keeping some certain level of availability of active and reactive power to ask it when there is a sudden change of demand. With new trends and changes in power sector from vertical and monopoly structure to horizontal and liberalizing model, with the increasing role of power generation from distributed generation (DG), the characteristics of ancillary services may need to be adapted and revised in an economic and efficient way.

The distribution systems are normally considered as being ***passive***. The distribution systems are stable as long as the transmission systems are. With newly introduced distributed generation, the distribution system becomes an ***active*** system with both energy generation and consumption at formerly exclusive load nodes. Furthermore, DG units, which have been treated as negative loads and are normally not required to provide any ancillary services or to participate into voltage and frequency control, are now considered to have more active roles in the power system control and operation [1], [2].

In this paper, possibilities of using DG units to participate into ancillary services are investigated. The secure operation of a power system is also taken into consideration with this participation. Simulations are done to illustrate the results. Finally, some suggestions are drawn from this study.

ANCILLARY SERVICES

Ancillary services are those services provided by generators and even interruptible loads, used to support and to ensure the power system in safe, secure and reliable operation. In new deregulated electricity markets, these services are both mandatory and should be competitive (e.g. by an auctioning process, call for tenders or via power exchanges) [3], [4]. The ancillary services can be frequency regulation, voltage control, spinning reserves, standby reserve, back-up reserve, load following, loss compensation, black-start capability, reactive power service, etc. [3], [4]. Adequate, efficient and available ancillary services for the system need help transmission system operators (TSO) or independent system operators to control system frequency and voltages within operating limits, to maintain the stability and to prevent from any black-out.

The impact and control scope of ancillary services on the power system can be local or global (system-wide). *Local ancillary services* can be voltage regulation, reactive power supply and loss reduction (by capacitors), provided and controlled locally where needed. *System-wide ancillary services* can be frequency control, active power reserves (spinning or standby), which have a global impact and are provided anywhere in the power system [5].

In most deregulated systems, transmission system operators are fully responsible for the ancillary service management and control. These activities are monitored to guarantee the transmission system in stable and secure operation modes. Distribution systems, at low level, are benefits from those activities as they are stable as long as the transmission systems are stable.

The distribution system formally considered as *passive* system becomes *active* with both power consumption and generation combined when there is a large portion of DG units connected.

Many DG technologies have both active and reactive control capabilities such as combined heat and power system using synchronous machines and doubly-fed induction generators used for wind turbines. Depending on the size of DG units and technologies, they can be employed to take part in primary or secondary voltage and frequency control. Furthermore, new market mechanisms affect the network operation topology and ancillary services of the power system.

Electrically excited synchronous DG generators can supply and control reactive power injecting into a system; while induction machines consume the reactive power from the system or capacitors connected at their terminals. The synchronous DG machines' capability to supply reactive power contributes to improving voltage stability, in contrast with induction machines that may reduce the voltage stability of a network.

One of the main purposes of developing DG in the long run should be to increase the reliability of the power supply. Customers want to have a continuous and reliable electric energy supply, especially for sensitive loads. Due to infrastructure costs and the willingness to pay by customers, the power suppliers can only guarantee a certain level of reliability. DG might be a good solution to reduce costs and to maintain or even to increase reliability in many cases. DG can be run in a *back-up* mode, parallel operation, or as a main supply. The portion of electrical power not supplied by DG is coming from the grid. DG can also operate to *shave peak demand* in order to avoid additional charges. Depending on the electricity tariff and the generation cost of DG, the DG owner could optimize how to operate at the lowest costs.

VOLTAGE SUPPORT ABILITY

In order to see how DG can contribute to ancillary services, an existing Belgian medium voltage distribution system segment is used to study (Figure 1). The system includes one transformer 14 MVA, 70/10 kV and four cable feeders. The primary winding of the transformer is connected to the transmission grid and can be considered as an infinite node.

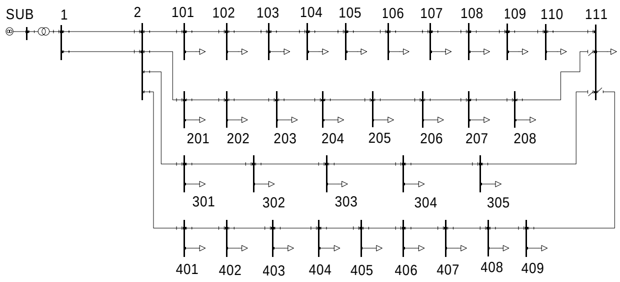

Figure 1: Medium voltage segment, radial operation

In order to see how the injected power from DG influences the voltage profile of a power system, a DG unit is connected at node 406 of feeder 4. It can be a synchronous, an induction or a converter connected generator. The total load in the system is 9.92 MW, 4.9 MVAr. Power injections of 3 MW and 6 MW are used to simulate with different power factors. The synchronous generator operates at a leading power factor 0.98 (injecting reactive power into the network). The induction generator operates at lagging power factor 0.95 (consuming part of its reactive power from the network, the remaining being supplied for instance by local capacitors). The converter-connected generator operates at unity power factor.

Figure 2 illustrates how the voltage at node 406 changes with different generated power and power factors. Compared to the case that DG only injects active power or operates at unity power factor, synchronous generators raise the voltage of the system faster due to the reactive power support. For induction generators, the voltage rise is smaller, and at a certain level of power generation, the voltage starts to decrease. This is due to the fact that induction generators need reactive power, leading to a reduction of the voltage rise.

A concern emerged is how we can use reactive power supply capability of DG to improve and control the feeder voltages. In terms of voltage rise, the generator that injects active power and absorbs reactive power seems to be better than the one that injects both active and reactive power.

However, the voltage rise problem also depends on the level of power injection and network characteristic. If there is an over-voltage in the system with the synchronous generator, it should reduce its excitation to absorb reactive power instead of injecting it into the system. It can also be operated in voltage regulation mode. However, this is difficult with small machines and may conflict with other voltage control strategies of the distribution system.

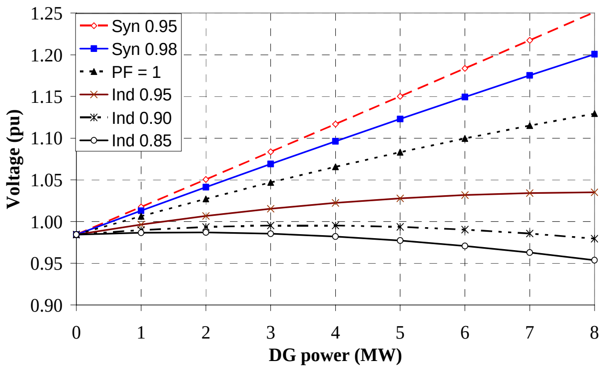

Figure 2: Voltage at node 406 with different power generation levels

LOSS COMPENSATION

The power losses in the system are calculated with different penetration levels and technologies of DG. The DG penetration level PL_{DG} can be calculated as a function of the total active power generation of DG 'P_{DG}' over the total active power load demand 'P_L':

$$PL_{DG}\ (\%) = \frac{\sum P_{DG}}{\sum P_L} x\ 100$$

Through the calculated results (Figure 3 and Figure 4), both active power loss and reactive-voltage drop in the distribution networks due to DG have almost the same characteristic. In general, at low DG penetration level, losses decrease and reach minimum points. But for higher penetration levels losses marginally increase and even can be higher than those in the base case. The losses increase because of the reversed currents from DG units to the main substation.

Active power loss and reactive-voltage drop cannot become zero in this case as DG units are only located at four nodes. The surplus power at each node is transferred to neighboring nodes, which in turn results in power losses. In addition, the substation still supplies reactive power to the load, or generators in cases of induction or power-electronics interface DG units, resulting in current flowing in line resistance and reactance.

The power loss reduction depends on the technologies used, as can be seen on the figures. The synchronous generators have the ability of reactive power supply. Both active and reactive power generation by synchronous machines reduce the power transferred from the substation. The generators connected via converters inject only active power but do not require reactive power, so the power loss reduction is smaller than in the synchronous machine case. The induction generators inject active power but require reactive power from the substation. The power loss reduction due to active power generation can only compensate the power loss increase due to reactive power consumption by the induction generators to certain extend.

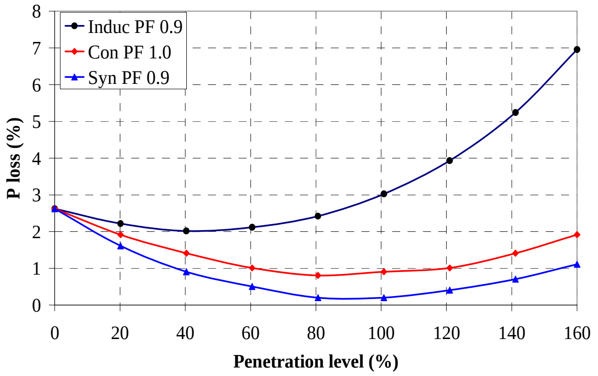

Figure 3: Active power loss with different DG penetration levels

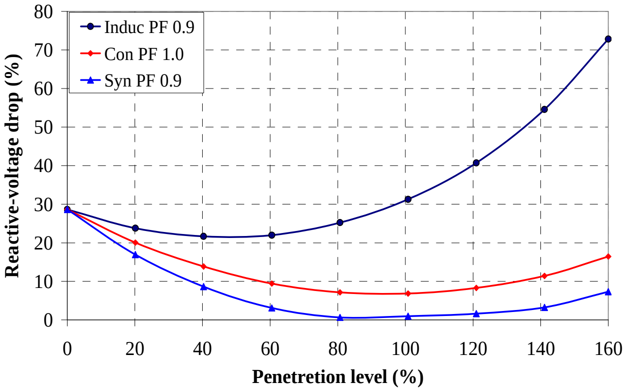

Figure 4: Reactive-voltage drop with different DG penetration levels

STABILITY SUPPORT ABILITY

Voltage Stability

Modern power distribution networks are constantly being challenged with the uncontrolled growing demand. Generally, distribution systems have a combination of loads (industrial, commercial, domestic, street lighting, etc.), and distinct changes in load levels occur at any time of the day at any part of the system. During peak loads, a small change in the load pattern may threaten the voltage stability of the system. The voltage instability problem is due to the voltage drop that occurs when the loading on a radial network exceeds its capacity for controlling the receiving end voltage. The voltage stability in distribution systems has received a lot of concern recently. With the newly introduced DG connected to distribution systems, it may be interesting to study how DG can contribute to or worsen the system voltage stability.

The system shown in Figure 1 is used. The voltage stability of distribution systems is studied for synchronous and induction generators with three connection points of DG units at nodes 108, 2, 406. The results of these three cases are compared to each other and the base case without any DG connection.

The total load of the system is 9.92 MW, 4.9 MVAr with a purely impedance load characteristic. The installed capacity of DG units in all cases is 3 MW. The voltage stability at node 111, the end of feeder 1, is studied. It is the furthest point from the substation and the weakest point of the feeder in term of voltage stability.

Through studies, DG is shown to generally increase the voltage and to support stability in the system (Figure 5 and Figure 6). Depending on the connection points, the influences of DG units on the voltage stability are different. DG strongly supports the voltage stability at nearby nodes (case with DG unit connected at node 108) and has less impact on distant ones (case with DG unit connected at node 2 or 406), when looking at node 111. This is also true for the other load characteristics and other nodes in the system.

The synchronous generator has a major impact on the voltage stability because of its capability of reactive power injection. On the other hand, the influence of induction generator based DG on voltage stability is smaller and has a limited benefit due to their demand for reactive power. However, it has a significant impact when it is connected close to node 111, considered as a weak area. This can be understood as the active power is not transferred across a long distance from the substation, resulting in reducing the voltage drop on the feeder, thus supporting voltage stability.

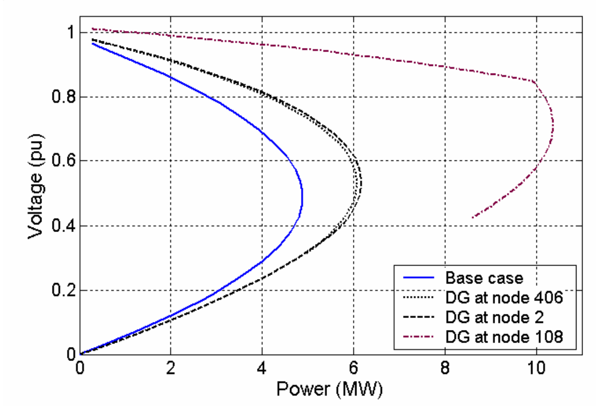

Figure 5: Voltage stability limit at node 111 with *synchronous* generators

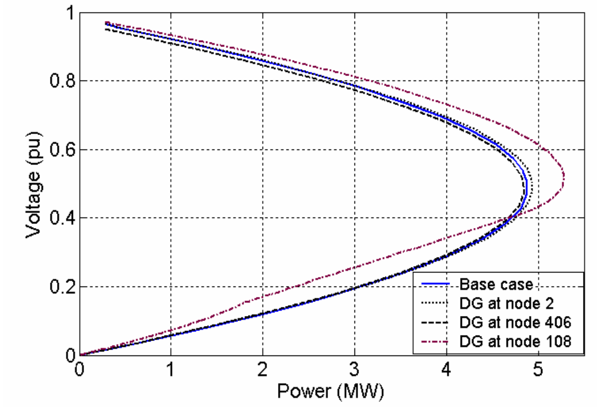

Figure 6: Voltage stability limit at node 111 with *induction* generators

Frequency Stability

Due to islanding protection requirement, a large disturbance may not lead to separate the system, but may result in large portion of DG units to be tripped. In a study, a line outage following a short circuit occurred on a network with eight nodes is modeled.

The system contains four central generators connected to bus 01 (Figure 7). In this study, synchronous machines are used. The load is kept unchanged when the penetration level of DG increases.

The power generated by DG leads to a reduction of power generation from central power units, thus reducing the number of online generators which have large frequency and voltage control abilities, and decreasing system spinning reserve.

Frequencies of central and DG units after subjecting to the disturbance are illustrated in Figure 8 and Figure 9, respectively corresponding to 44.4% and 50% of DG penetration level with frequency-relay setting at 49/51 Hz, delay 1.0 s. The system totally collapses after the disturbance for a few seconds when the DG penetration level is high and less number of central units. The question here is how to use DG units to contribute in frequency control and to help to maintain the secure operation of the system. In study [6], the authors recommend a large setting window and a long tripping delay of DG protection in order to allow high DG penetration and increase network stability. One concern is how we can allow DG units to participate and contribute to the frequency regulation and whether it should be allowed that DG remains to be online during large disturbances due to islanding protection requirement. New generation of wind technologies have the ability of ride-through, but their contribution to frequency and voltage control is still very limited.

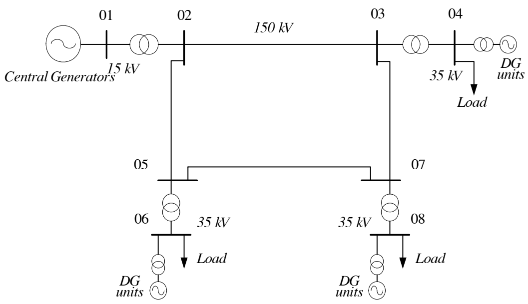

Figure 7: 8-bus system used to study frequency stability

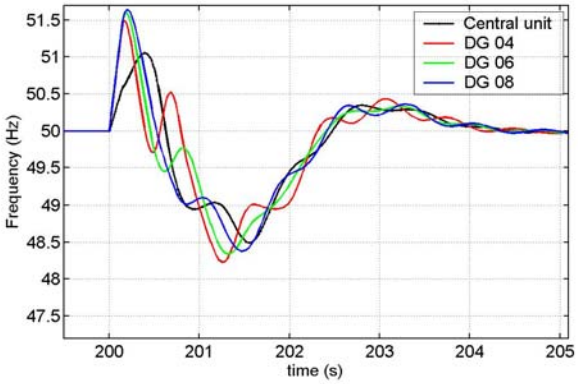

Figure 8: Frequencies of central and DG units after subjecting to a line outage following a short circuit (*stable* case)

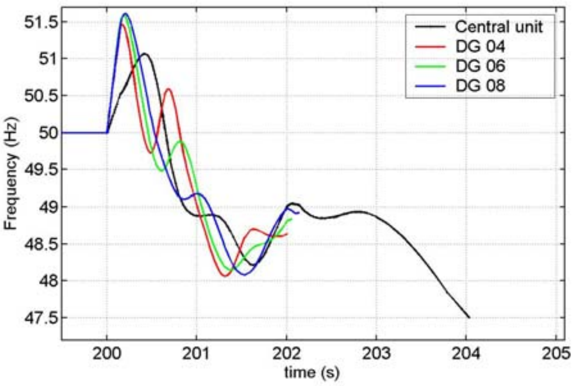

Figure 9: Frequencies of central and DG units after subjecting to a line outage following a short circuit (*collapsed* case)

BLACK-START AND NETWORK RESTORATION

Black start is the capability of a generator to start up without any help from other system. DG units with induction machines do not have this ability, as they need voltage and reactive support from grid to magnetize the magnetic circuit. The DG units that are normally used for back-up purposes often have black-start ability. However, their capacities are generally small and can meet some level of critical loads of the customers. They cannot restore a large portion of distribution loads, but they can participate and contribute to the network restoration process.

Furthermore, the restoration from *downstream* by using DG units, coordinating with *upstream* restoration by large central units, may fasten the restoration duration, thus shorten the outage duration of the system load. However, the problem of re-synchronizing the downstream and upstream systems should not be underestimated.

CONCLUSIONS

Even with a small size, the impact of DG is significant on the locally controlled variables such as voltage regulation, loss reduction, and voltage stability limit of the distribution system. When the DG penetration level is high, it may impact on the frequency control and stability of the power system due to islanding protection leading to a large portion of power generation out of service and the remain central units cannot cover the load.

Depending on the network and load characteristics, the network operators may deploy DG and coordinate with other control devices to regulate the system voltages and require DG to operate at some power factors in order to reduce the system loss. The connection of DG units, which may have active and/or reactive power control ability, can be deployed for the ancillary services.

After a system outage and faults are eliminated, DG may participate to the restoration process from downstream in order to bring and restore the power system into service rapidly.

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