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Distributed Generation and Power Quality – Case Study

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C16.1 DISTRIBUTION NETWORK

A segment of an existing Belgian medium-voltage distribution system is used to study the power quality and voltage stability with different distributed generation (DG) technologies (Figure C16.1). The system includes one transformer of 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. Normal operation of the distribution system is in radial mode and the connections at node 111 with feeders 2, 3 and 4 are normally open.

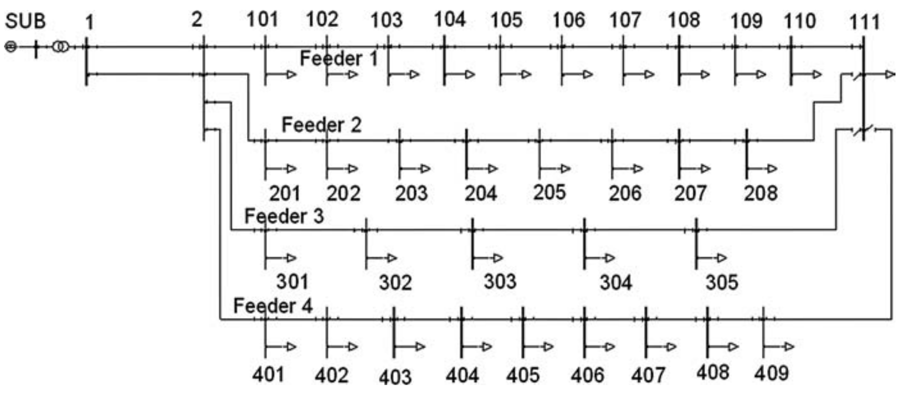

Figure C16.1 Tested distribution system

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C16.2 STEADY-STATE VOLTAGE RISE

A DG unit is connected at node 406 of feeder 4. It can be a synchronous or induction generator. The total load in the system is 9.92 MW, 4.9 Mvar. Both synchronous and induction generators are simulated at different output power at 3 MW and 6 MW. The synchronous generator has a power factor of 0.98 (injecting reactive power into the network). The induction generator has a power factor of 0.95 (consuming reactive power from the network). Compared to the base case without any DG connected, the active power of the DG raises the voltages in feeder 4 (Figure C16.2). For the synchronous 6 MW, overvoltages occur at node 406 and its neighbors.

Figure C16.3 illustrates how the voltage at node 406 changes with different generated power and power factors. Compared to the case where DG only injects active power or operates at unity power factor, synchronous generators raise the voltage of the system faster due to 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, being negative in (16.4), yielding a reduction in the voltage rise.

Through this study, DG can improve and support the voltage profile of the distribution system. It can be seen that the impact of induction is less serious than with synchronous generators in terms of voltage rise (Figure C16.4). If there is an overvoltage in the system with the synchronous generator, it has to operate with underexcitation and to absorb reactive power instead of injecting it into the system.

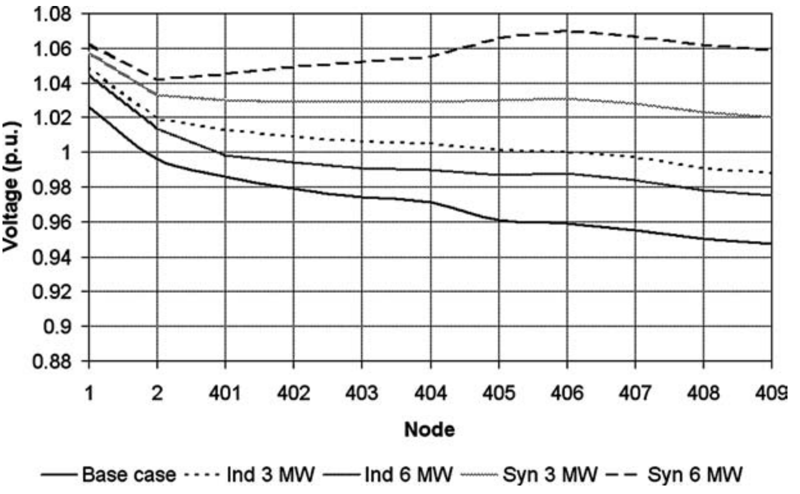

Figure C16.2 Voltage profile of feeder 4 with DG connected at node 406

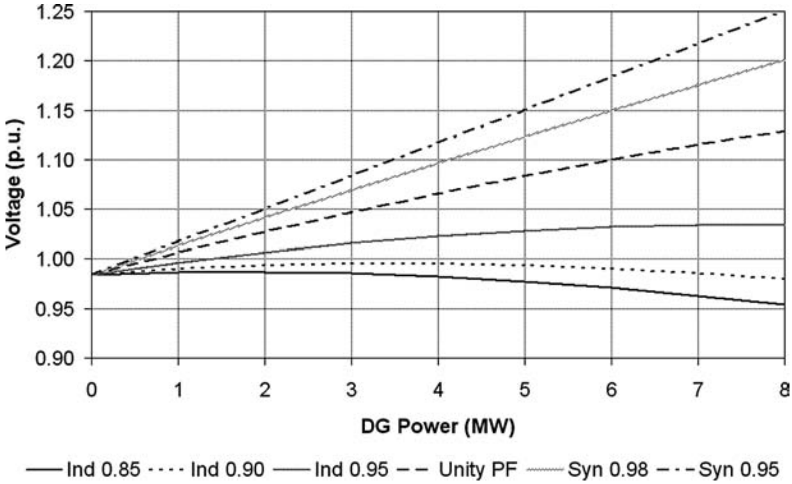

Figure C16.3 Voltage at node 406 with different power factors

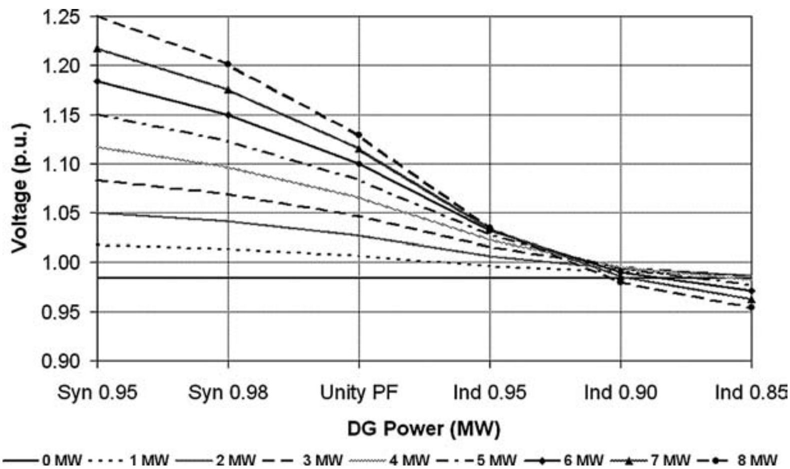

Figure C16.4 Voltage at node 406 with different power generation levels

C16.3 VOLTAGE FLUCTUATIONS

In order to illustrate the voltage fluctuation problem with DG, a photovoltaic (PV) system is used. The reactive power is produced by a capacitor of the inverter's grid filter and is almost constant, so the PV system is treated as a power quality node with negative power. The PV power is calculated from an average 5 s of irradiance data measured during one year in Leuven, Belgium. In this study, a PV array with 50 kW rated peak power is connected at node 304. Figure C16.5 shows the one-hour power output of the PV system at noon on a slightly cloudy summer's day. In order to isolate the voltage fluctuation impact of PV from short-time load variation at individual nodes, the loads are assumed constant during the calculation. The total load in the system is 4.4 MW, 1.9 Mvar. In Figure C16.6, the voltage fluctuation corresponds to the fluctuations of injected active power of the PV system.

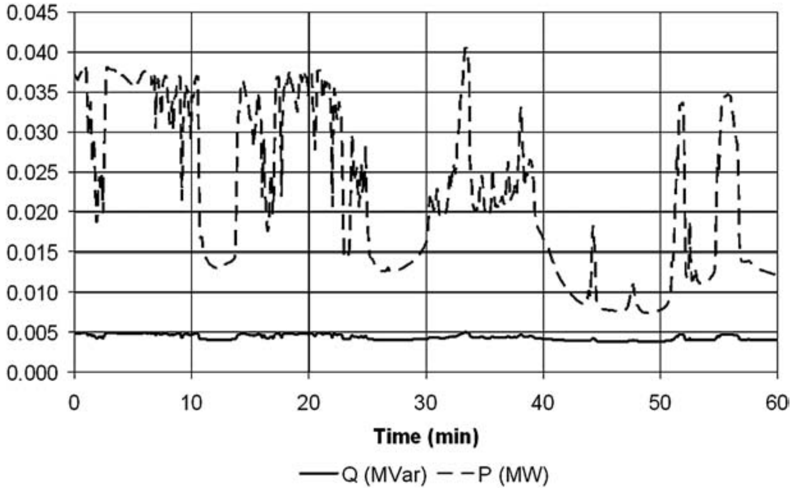

Figure C16.5 Injected power of PV at node 304

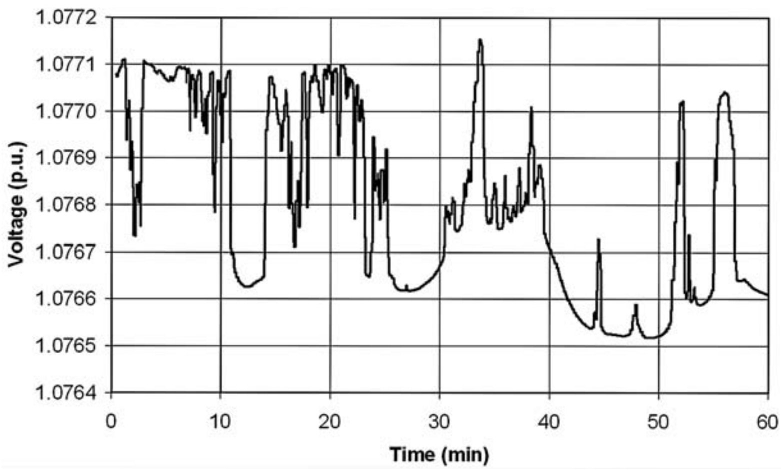

Figure C16.6 Voltage at node 304

At times when clouds cover the sun, the power generated can quickly drop by 60 %, causing sudden variations in node voltages in the range of 0.1 %. The installed capacity of PV in this study is rather low compared to the capacity of the distribution system and the loads, so the value of voltage fluctuation is quite low. However, with a high connection density or the connection of a large PV system, the voltage fluctuation problem might become severe [27].

DG with fluctuating power output as in wind or photovoltaic systems may introduce stochastic fluctuations, and flicker, in the grid voltage in the range of seconds up to an hour [10]. Depending on the power output of DG, in combination with distribution network characteristics and load profiles, over- or undervoltages of several-minutes' persistence might occur. In that case, the introduction of DG might be combined with load management and storage.

C16.4 VOLTAGE DIP

C16.4.1 Opening One Branch

In order to investigate the interaction between DG technologies and different load characteristics, a total DG capacity of 30 % of the total system load is equally distributed at nodes 108, 204 and 406. Simulations have been carried out for induction and synchronous generators. One of the 1–2 lines is opened at $t = 100$ s. The distributed generators are connected at nodes 108, 204 and 406 with a rated power of 1 MW for both synchronous and induction generators.

The voltage dips are highest with a constant power load characteristic and lowest with an impedance load characteristic for both synchronous and induction generators (Figure C16.7 and Figure C16.8). With the synchronous generators, after a short voltage dip, the voltage recovers close to its initial value. For induction generators, the voltage does not recover due to the lack of reactive power support. There is not so much difference between a voltage dip in the base case and with DG, being around 1 %. So the connection of DG in the distribution

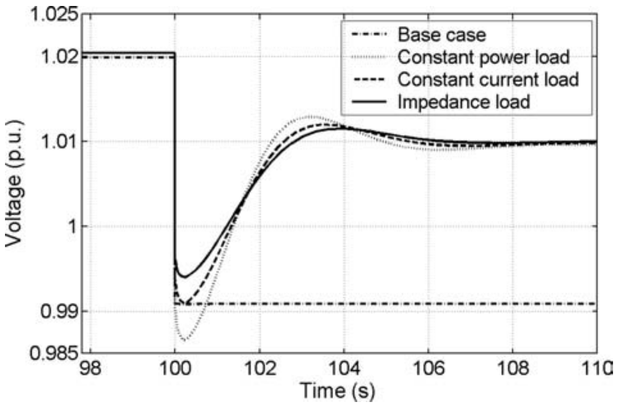

Figure C16.7 Voltage dip at bus 2 with synchronous generator

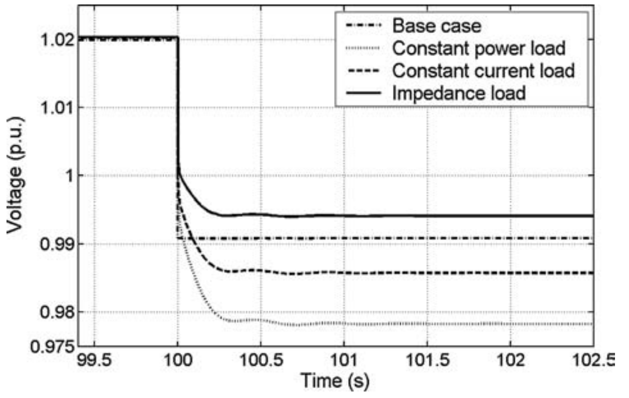

Figure C16.8 Voltage dip at bus 2 with induction generator

system does not significantly affect the dynamic voltage stability, and, in most cases, it reduces the value of the voltage dip.

C16.4.2 Generator Start-up

In order to see the voltage dip problem when a DG unit starts up, an induction generator connected at node 108 with rated power of 3 MW is tested at a lagging power factor of 0.9. This simulation shows how large the influence can be in an extreme case where a customer has a large induction DG unit and does not follow a correct start-up method. When the induction generator starts up, it causes a transient and a voltage dip up to 40 % in the system lasting for several seconds (Figure C16.9). It is due to an initial magnetizing inrush transient and power transfer to bring the generator to its operating speed [12]. This leads to a major problem for sensitive loads connected near the DG unit. If the distribution system is equipped with an undervoltage relay and the DG unit has islanding protection, the voltage dip may lead to a malfunction of the protective relay resulting in an outage of the system. A soft-start circuit is required for large connected induction DG.

C16.5 STATIC VOLTAGE STABILITY

The voltage stability of distribution systems is studied for synchronous and induction generators with three connection points of DG units at nodes 108, 2 and 406. The results of these three study 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 the 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 terms of voltage stability. It is observed in [17] that for the voltage computation and voltage stability analysis of a radial system, a constant impedance load model can be used. It is also observed that the voltage stability of the network has similar characteristics with different load models (constant impedance, current and power loads). The voltage stability impact of DG with constant impedance loads is illustrated.

Through studies, DG is shown generally to increase the voltage and to support stability in the system (Figure C16.10 and Figure C16.11). The location of DG has a major impact on the voltage stability of the system. 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 (the case with DG unit connected at node 108) and has less impact on distant ones (the 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.

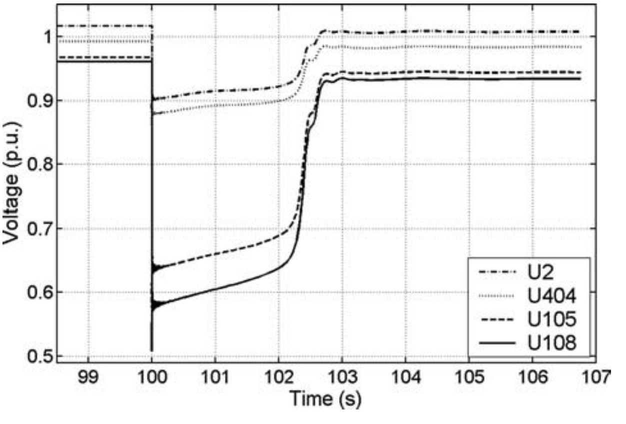

Figure C16.9 Voltage dips at different nodes when starting up an induction generator at node 108

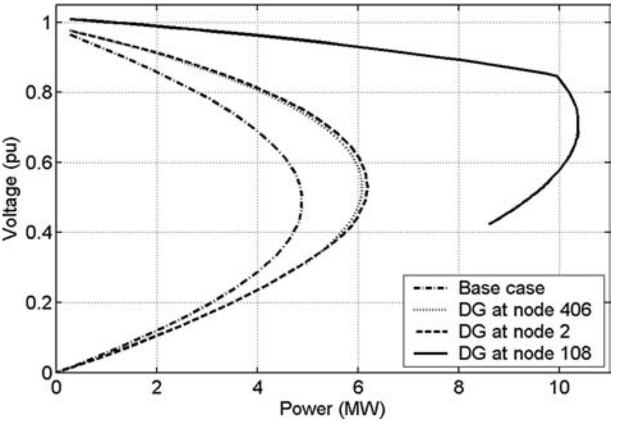

Figure C16.10 Static voltage stability at node 111 with a synchronous generator

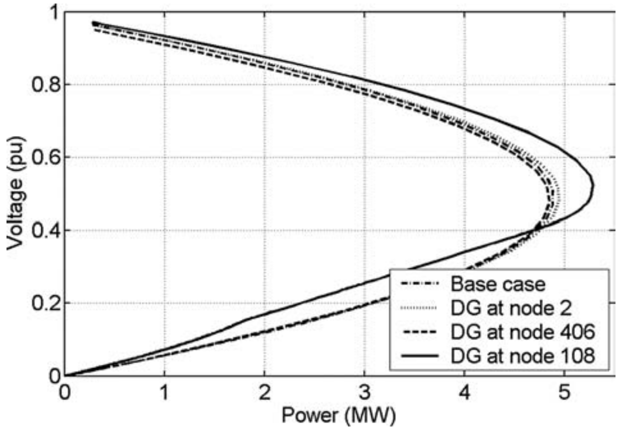

Figure C16.11 Static voltage stability at node 111 with an induction generator

The synchronous generator has a large impact on the voltage stability because of its capability of reactive power exchange. On the other hand, the influence of induction-generator-based DG on voltage stability is smaller and has a limited benefit due to the demand for reactive power. However, it has a significant impact when it is connected close to node 111, considered as a weaker area. This can be understood because the active power is not transferred across a long distance from the substation, resulting in a reduction of the voltage drop on the feeder, thus supporting voltage stability. This allows the distribution system to withstand higher loading conditions and defers the construction or upgrade of new transmission and distribution infrastructures.

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