VOLTAGE REGULATION IN DISTRIBUTION NETWORKS WITH DISPERSED GENERATORS

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ABSTRACT

Various investigations have showed that dispersed generators integrated into utilities’ distribution networks could affect the host distribution networks in number of ways. This paper reports an investigation of the voltage regulation possibilities in the distribution networks with dispersed generators. In addition, the impact of different voltage regulation actions on loss allocation in the distribution networks with dispersed generators is also reported. Results obtained from several case studies using IEEE 34 nodes test network are presented and discussed.

Key words: voltage regulation; dispersed generations; power flow; loss allocation.

INTRODUCTION

Several investigations have showed that dispersed generators (DGs) integrated into utilities’ distribution networks (DNs) could affect the host DNs in number of ways [1-9]. Previous experience has shown that the integration of DGs into DNs could create safety and technical problems. They may contribute to fault currents, cause voltage flickers, interfere with the process of voltage control, increase losses, etc. Since the DNs with DGs are not passive, all issues about planning, building, maintaining and operation of the DNs become very interesting and need a re-investigation. Actually, overall model of the distribution system should be renewed, since the impact of DGs on the DNs expansion planning and operation is significant.

The Distribution Management System (DMS) functions like load (state) estimation, power flow calculation, network reconfiguration, supply restoration, fault analysis, relay setting, Q-V regulation etc. are significantly affected by the DGs in the DN. It means that the DMS functions should be re-considered and probably modified in order to respect the presence of DGs in the DNs. For example, the presence of DGs in the DN will improve the quality of state estimation in the DN, since the voltages in the DG’s nodes are known. Power flow calculation is of course affected by the DGs, as well as, the network reconfiguration in order to minimize the power losses. Supply restoration after the fault of feeder or supply transformer, should respect the presence of the DGs in the DN as well, since alternate variants of power supply could be quite different comparing to the passive DNs. Similarly the DGs change the voltages and reactive power flow in the DNs and consequently Q-V regulation should be re-considered, etc.

This paper reports the voltage regulation issues when DGs are integrated into DNs. The impact of the DGs on the voltage regulation, reactive power flow and loss allocation performances of the distribution systems in steady state is also investigated. Results obtained from several case studies using IEEE 34 nodes test network are presented and discussed.

VOLTAGE REGULATION

The basic tool for analyzing the voltage regulation performances of DNs with DGs is an efficient power flow program. The DG may operate in one of the following modes: 1) In parallel operation with the feeder where DG is designated to supply a large load with fixed real and reactive power output; 2) To output power at a specified power factor; 3) To output power at a specified terminal voltage.

Considering power flow computations, the DG node in the first two cases can be represented as a PQ node. It requires just a little modification in the power flow algorithm, actually the current is injected into the bus. In the third case where the source controls the voltage magnitude at the corresponding node, the node is referred to as a PV node. If the computed reactive power generation is out of the reactive generation limits, the reactive power generation is set to that limit and the unit acts as a PQ node. Some dispersed storage units may also act as a constant current but for purposes of the power flow the PQ model is adequate. In last decade, different procedures for handling PV nodes have been proposed [10-14]. Special single-phase and three-phase power flow methods have been developed for radial and weakly meshed network analysis. Experience showed that very good results in handling PV nodes in large-scale DNs are obtained using the backward/forward procedure, i.e. branch-oriented methods. These methods may be classified as follows: current summation methods, power summation methods and admittance summation methods [14]. In the proposed methodology for determining the impact of DGs on the voltage regulation performance, the efficient and robust compensation method proposed in [11] is applied. In this method, PV node sensitivity matrix is used to eliminate voltage magnitude mismatch for all PV nodes. The problem of compensating PV node voltage magnitude is transferred to the determining reactive current injection for each PV node, so that the voltage magnitude of this node is equal to the scheduled value. Since relation between reactive current and voltage magnitude of the DG is nonlinear, desired reactive current of the DG is determined iteratively.

Connection of the DGs in the DNs can result in voltages that may be out the statutory limit [15-17]. Generally there are two cases of DG that can operate in the DNs: induction generator (wind-turbine) or synchronous generator (gas, diesel turbine etc.). In case of wind-turbine, DG’s voltage can be greater than substation high voltage/medium voltage HV/MV), namely voltage rise at the DG node can occur. In case of synchronous generator substation voltage is usually maintain greater than DG node voltage. Voltage rise - mismatch between generator voltage and substation voltage, $\Delta V_g$ in case of induction DG is given by equation (1) [15]. The voltage

\[
\Delta V_g = \frac{V_{gs} - V_{gs}}{V_{gs}}
\]
increase of generator reactive power import \( P_g \) where:

\[
\Delta V_d = \left\{ \frac{(P_r - P_g) R - (Q_r + Q_g)}{\sqrt{X}} \right\} V^* g
\]

\[
\Delta V_r = \left\{ \frac{P_r - P_g}{\sqrt{X}} + \frac{Q_r - Q_g}{\sqrt{X}} \right\} V^* g
\]

where:

- \( P_g \) is real power of the DG;
- \( Q_g \) is reactive power of the DG (injection or import);
- \( P_r \) and \( Q_r \) are real and reactive consumer loads at the DG node;
- \( Z = R + jX \) is the line impedance between substation HV/MV and the DG node;
- \( V_s \) is the voltage at the substation HV/MV,
- \( V_g \) is the voltage at the DG node,
- \( V_d \) is voltage drop in case of synchronous DG,
- \( V_r \) is voltage rise in case of induction DG,
- \( V_{P_r} = V_r - V_g \) is voltage drop in case of synchronous DG.

There are several methods for reducing voltage rise in case of wind turbine DG (1): reduction of generator power input \( P_r \), increase of generator reactive power import \( Q_g \) or voltage regulation via load control in the DG node [15]. The generation output is reduced only at critical times to maintain satisfactory voltages. Increasing the generator reactive power import to neutralize voltage rise from the real power injection is done by static VAr compensators, switched capacitor banks or via existing inverters. Power factor control allows full generation output. Load control in reducing voltage rise is a new method [15]. Actually, when feeder voltages are at their limit, additional load is switched on to reduce voltage. Usually for reducing voltage drop in the DNs in case of synchronous DG is increasing generator real and reactive power input \( P_g, Q_g \) (2).

**LOSS ALLOCATION**

One of the interesting issues about DGs in the de-regulated power energy market, is problem of loss allocation to loads and generators in the DN. Although the loss allocation issue is naturally more addressed to the transmission systems [18], after introducing DGs and open access electricity networks in last decade, distribution system loss allocation is getting more interesting problem [19]. Moreover, in the de-regulated power industry, loss allocation in the DNs becomes very significant issue since the losses in the medium voltage DNs are in range of 2-5 \%, while the losses in the low voltage network sometimes exceed 10-15 \%. The main difficulty in allocating losses to loads is that, regardless of the approach, the final allocation always contains a degree of arbitrariness. This is the consequence of the fact that distribution, as well as, transmission losses are a non-linear function of the node injections. As it is concluded in [18] it seems that issue of fairness will probably never be fully resolved by any loss allocation method.

An important characteristic of the methods (DLC and MLC) presented in [19] is the possibility of negative loss allocations. Negative allocation provided monetary incentives to those DGs “well” positioned in the network. On the other side, DGs and loads “poorly” placed, receive higher loss allocations. If the node has neither load nor generation the loss allocation is zero. Since in the DN power flow calculations, losses are deemed to be supplied from the transmission network that is taken as a slack node, the loss-related charges for this node is zero. In other words, total power losses in the DN are insensitive to changes in active and reactive injections at the slack node.

**APPLICATIONS**

**Test Network**

Test network used in all case studies is the IEEE 34-node test feeder [20], Figure 1.

For the simplicity reason the in-line auto-transformer 24.9/4.16 kV/kV from the original IEEE 34 test feeder is replaced with the line and the network is modeled with the single voltage level. Base voltage of the network is \( V_b = 24.9 \) kV, and the reference voltage is \( V_{ref} = 25.647 \) kV. Test network used in all case studies is the IEEE 34-node test feeder [20], Figure 1.

**Case Studies**

Voltage regulation in the DN by DG’s reactive power control and voltage control in different nodes (23 and 26) is simulated. In addition, the impact of different voltage regulation actions on loss allocation in the DN with DG is also investigated. In this research efficient and robust power flow algorithm [11] for DN with DGs is applied. In order to observe losses in the DNs with DG, direct loss coefficients (DLC) method, presented in [19] is applied. The following case studies are considered:

1. IEEE 34 DN without DG;
2. IEEE 34 DN with DG at node 23;
3. IEEE 34 DN with DG at node 23, without capacitor at node 28;
4. IEEE 34 DN with DG at node 23 without capacitors.
Results

The obtained results show the influence of the DG on the performance of the distribution system (voltage profile, reactive power, losses). Figure 2 shows voltage profile in the IEEE 34 DN for the different voltage level of the DG at node 23. Figure 3 shows voltage regulation by reactive power control in the PV node 23, \( P_g = 150 \) kW.

Figure 4 shows the injected reactive power in the reference node and DG node for different case studies, and Figure 5 shows total real and reactive power losses \( P_{loss}, Q_{loss} \) for the different cases (1-4). It should be noted that the DGs acts reducing losses and currents in the feeder until a determined level of voltage and power injection, then above these levels the losses and currents in the main part of the feeder will increase, due to reactive power flow from the DG to the substation.

The loss allocation for each node with/without DG in the node 23, for the cases 1 and 2, is showed in the Figure 6. It can be observed that the node 23 received a negative loss allocation value when the DG is integrated and, as the total loss was reduced then losses allocated for each node was also reduced.

Figure 7 shows voltage profile with/without DG in the node 23, with voltage control at node 26, for the cases 1 and 2.
This paper reports some aspects of integration of the DGs in the DN. Voltage regulation, as well as loss allocation in the DN with DG are investigated. Results show that DG in the DN interferes with the process of voltage control. The impact of different voltage regulation actions on loss allocation in the DN with DG is also investigated. In this research direct loss coefficients (DLC) method is applied. Important characteristic of the DLC method is the possibility of negative loss allocations to those DGs “well” positioned in the DN. The results show up that the losses in the DN can be significantly reduced and, then the loss allocation for each node is also reduced. Hence the DG node has received monetary incentive for reducing the total losses in the DN. The DG in the considered case studies can significantly reduce power losses, improve voltage profile and increase current reserve of the feeder, depending on the level of voltage and power injection on the DG node. Therefore, the integration of the DGs into DN could create technical and safety problems, and then the operation of the DN becomes very interesting and needs a re-investigation.

REFERENCES