PERFORMANCE ASSESSMENT OF DISTRIBUTED GENERATION UNITS TO ENHANCE LOADABILITY OF DISTRIBUTION NETWORK UNDER UNCERTAINTIES

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ABSTRACT

In this paper, the impact of different DG technologies on operational characteristics, such as voltage profile, power losses and voltage stability margin is evaluated through introduced technical indices. These indices presented as voltage profile improvement index (VPII), line loss reduction index (LLRI) and voltage stability margin index (VSMI) are discussed in the paper.

A case study is conducted on IEEE-30 bus test system. The system is modeled with all detailed parameters using MATLAB. Distributed generation units are installed at proposed locations with specific maximum capacity within the IEEE-30 bus test system. An analysis is performed to find the weakest buses in the system where the DG units are located in these buses to increase the loadability of the network. The research shows that the loadability margin varies with type of DG and its reactive power support where synchronous generator units compared to asynchronous units have a large impact on the voltage stability margin. The paper investigates the impacts of the synchronous generators DG units operating in voltage control mode through the introduced technical indices for two configurations. In the first configuration, the effect of each DG unit operating with nominal power on operational indices is compared. In the second configuration, the uncertainties in the location of DG units driven by customers and their strategy for operating their DG units are investigated based on a Monte-Carlo method. In this configuration, the assigned generated power from each DG unit varies randomly in the system according to the demand.

INTRODUCTION

Due to recent changes in the electric distribution systems, new opportunities have been created in the power industry to employ distributed generation (DG) integration for achieving a variety of benefits [1]. DG can come from renewable or non renewable energy resources, using both modern and conventional technologies. DG units are owned either by distribution network operators (DNOs) or by non-DNO entities such as customer DG developers [2]. In this paper, the stochastic behaviour of the customer-owned DG units in the system is investigated through an uncertainty analysis. Due to the fact that customers have different strategies for operating their DG units, the state of DG units and their generated power would be a random process. Therefore, a Monte Carlo-based method is used for stochastic modeling of the random operation of such DG units and evaluating the steady state parameters of the network [3].

The primary energy of *DG* units may be injected to the grid directly using synchronous or asynchronous generators or via a power electronic interface. The reactive power support of DG units has an important role in the loadability or voltage stability aspect. By enhancing loading margin, distribution companies or power utilities can optimize resources and maximize profit [4].

In this study, the voltage sensitivity factor calculation is performed to identify the weakest buses in the system. The DG units are placed in these buses to enhance the loadability of the system.

APPLIED APPROCHES AND TEST SYSTEM

The study is performed based on the application of the following two approaches:

- The impacts of different types of DG units on network performance are investigated. The quantified technical factors through practical indices are steady state voltage profile, electrical power losses, and voltage stability.
- The uncertainties in the performance of DG units driven by customers and their strategy for operating their DG units are investigated based on a Monte-Carlo method.

According to the characteristics of power production, DG can be specified as a constant power factor model, variable reactive power model or constant voltage model in the load flow analysis [4]. Traditionally, DG has been considered as not having the capability to control voltage, and therefore, it has been modeled in power flow studies as a negative load, i.e. as a PQ node. However, if DG is able to control reactive power, the node where DG is connected should be modeled as a PV node.

In this work, several indices will be computed in order to describe the impacts of DG units on the distribution system at maximum network demand.

Voltage Profile Improvement Index (VPII)

Voltage Profile Improvement Index (VPII) has been defined as the ratio of a measure of the voltage profile of the system with DG to the same measure with no employed DG [5]. The voltage profile is computed based on the following equation:

$$VP_i = \frac{(V_i - V_{\min}) \cdot (V_{\max} - V_i)}{(V_{nom} - V_{\min}) \cdot (V_{\max} - V_{nom})} \quad (1)$$

where VP_i is the voltage profile of i^{th} node, V_{min} and V_{max} are the minimum and maximum permissible voltages of the system nodes and V_{nom} is the nominal or desired bus voltage, typically taken as 1.0 pu. The overall voltage profile index for the system is defined as:

$$VP = \frac{1}{N} \cdot \sum_{i=1}^{NB} VP_i \quad (2)$$

The voltage profile improvement index for the overall system is defined as:

$$VPII = \frac{VP\ with\ DG}{VP\ without\ DG} \quad (3)$$

Line Loss Reduction Index (LLRI)

One of the important benefits of DG in distribution system is the loss reduction, both real and reactive power losses. The resistance of the lines causes the real power loss, which reduces the efficiency of transmitting energy to customers and plays an important role in economic evaluation of DG benefits. The total line loss in the system can be expressed as:

$$LL = \sum_{i=1}^{N_g} P_{G_i} - \sum_{i=1}^{N_l} P_{L_i} \quad (4)$$

The line loss reduction index (LLRI) then is defined as [5]:

$$LLRI = \frac{LL\ with\ DG}{LL\ without\ DG} \quad (5)$$

with the loads being the same in both cases (with and without DG). Thus an LLRI less than 1.0 signifies a reduction in line loss.

Voltage Stability Margin Index (VSMI)

If a power system operates stably at a certain loading level, an increase in the load in a particular pattern would cause voltage instability. P-V curves have been traditionally used as graphical tools for studying voltage stability in electric power systems. The loading margin can in principle be calculated by starting at the current operating point, making small increments in loading and recalculating the load flows at each increment until the nose of the P-V curve is reached. The voltage stability margin is then the total increment in loading [6]. Fig.1 conceptually shows the impact of a synchronous DG generator on voltage stability of a hypothetical node. Installation of the DG unit moves the operation point from point A to point B on the associated *P-V* curve, which results in an increase of the node voltage from V_0 to V_{DG} and voltage stability margin from W_0 to W_{DG}.

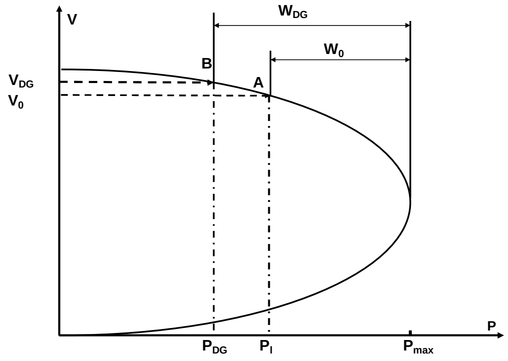

Fig. 1. Typical PV curve.

The voltage stability margin improvement, VSMI, can be defined as:

$$VSMI = \frac{VSM\ with\ DG}{VSM\ without\ DG} \quad (6)$$

VSMI more than 1.0 signifies an improvement in loadability margin.

Test system and case study

The proposed evaluation method has been applied on the IEEE 30-bus test system. The system has six generators, 24 load buses and 41 transmission lines. The load flow data of the system is included in [7]. The single line diagram of IEEE 30-bus system is shown in Fig. 2. A loading condition of 283.4MW and 126.2MVAr is assumed as the base case. The voltage limit of ±5% is applied at load buses. The DG units are placed in the weakest buses of the system based on voltage sensitivity factor calculation as:

$$VSF_k = \frac{dV_k}{\sum_{i=2}^{NB} dV_i} \quad (7)$$

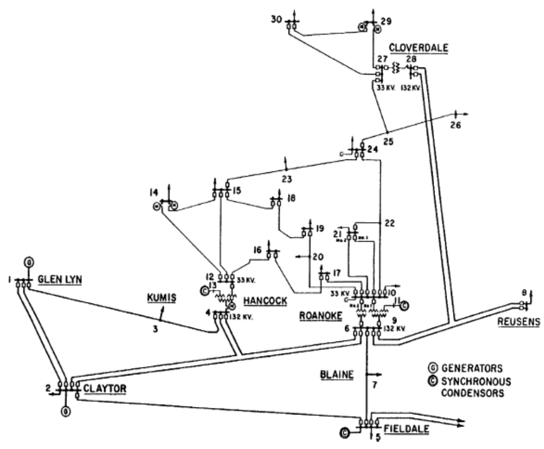

Fig. 2. IEEE 30-bus system.

These buses are 26, 29, and 30. The maximum capacities of DG units placed in these buses are assigned 20, 10 and 30 MW, respectively. The case without installing the DG units is selected as base case. The PV curves of these three buses before DG installation are depicted in Fig. 3.

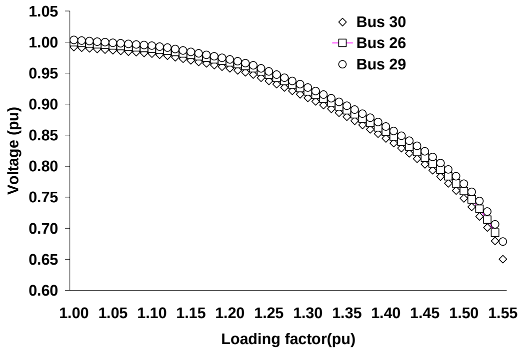

Fig. 3. PV curve of candidates buses before installation of DG.

In this figure, it is clear that at the lower loading factors, the voltage declines slowly with the load, whereas, near to the bifurcation point that corresponds to λ=1.5515 pu, the voltage drops rapidly. The main factor causing voltage collapse is the inability of the power system to meet the demand of reactive power where, at this point, several generators fulfilled their *Q* limits. The increase of real power at load areas and absence of reactive power support will cause voltage collapse.

RESULTS AND DISCUSSIONS

To evaluate the impacts of different DG technologies through introduced indices, the DG units are modeled as PQ or PV buses. In part A, the impacts of DG types modeled as PQ or PV buses are investigated. The DG considered in Part B and C is the synchronous machine whose voltage can be controlled with dispatchable power output such as gas turbines for CHP applications. This type of DG is modelled as PV bus.

A. Impact of DG types on evaluated indices:

The impacts of different DG types on the indices are summarized in Table 1. Due to reactive power support, synchronous generators raise the voltage of the system more in comparison with the case that DG only injects active power. The negative value of VPII index of synchronous generators shows that the overvoltage is occurring in the system. For asynchronous generators, the voltage rise is smaller than synchronous generators and at a certain level in power factor 0.9, the voltage starts to decrease. The evaluated VPII for asynchronous generators decreases as the power factor changes from 0.95 to 0.9.

The synchronous generators lead to the larger reduction in losses because these types of generators supply the active and reactive loads locally, decreasing the magnitude of currents in the feeders. The usage of asynchronous generators does not cause a great reduction in the active power losses; since these generators consume reactive power from the network, increasing the magnitude of the currents circulating in the feeders.

Table 1: Evaluated indices for different DG types and operation modes.

DG Type & operation mode	VPII	LLRI	VSMI
Synchronous-voltage control	1.218	0.8537	1.2923
Synchronous- unity power factor	0.4568	0.7845	1.1168
Synchronous-power factor 0.95	-1.6797	0.7708	1.2285
Asynchronous-power factor 0.95	1.1979	0.8798	0.9094
Synchronous-power factor 0.9	-3.0087	0.7839	1.2604
Asynchronous-power factor 0.9	0.715	0.9728	0.7339

The results show that the presence of the DG improves the system voltage stability margin when it generates reactive power. The synchronous machine working in voltage control mode has the highest VSMI index which is 1.2923. The asynchronous generators have lower VSMI index than the others, which indicates that, by absorbing reactive power, the DG has increased the reactive power transmission and made the voltage stability margin worse.

B. Impact of each DG unit on evaluated indices:

The evaluation of indices for each DG unit is presented in Table 2. As can be seen in this table, the DG unit in bus 26 has improved voltage profile by 10.83%, the best improvement amongst all. The DG unit in bus 30 with 10.24% is the second one and the DG unit in bus 29 with 3.98% is the third one. From LLRI index's point of view, the reduction in losses for DG units in buses 30, 29, 26 is 13.32%, 7.02% and 5.37%, respectively; meaning that DG unit in bus 30 has the most reduction in losses.

As for voltage stability margin, the DG unit in bus 30 is the best between all with 15.28% improvement following with DG unit in bus 26 with 5.3% improvement. The DG unit in bus 29 shows no improvement in voltage stability margin. These results show that the value of each DG unit with respect to the evaluated indices and the impact on the system's performance is dependent on DG location and to some extent to its capacity.

C. Uncertainties assessment in state and power generation of DG units

Considering the stochastic behaviour of customer-owned DG units, a Monte Carlo-based power flow algorithm is used to deal with the uncertainties of the system operation. The steady state parameters of the system are calculated through power flow solution and Monte Carlo simulation. The power flow equations are solved using Newton-Raphson iteration with the random features (DG units at on/off state and DG units' generated power). The applied Monte Carlo-based method is briefly discussed in [3, 8].

Table 2: Evaluated indices for each DG unit operating individually in the system.

DG location and maximum capacity	VPII	LLRI	VSMI
Bus 29 and 10 MW	1.0398	0.9298	0.9892
Bus 26 and 20 MW	1.1083	0.9463	1.053
Bus 30 and 30 MW	1.1024	0.8668	1.1528

In this paper, through the applied Monte Carlo method the uncertainties with respect to the state and power generation are investigated for three cases. A sample of the convergence process for the total DG penetration level exported to the system, for all experiments, related to Cases 1 and 2 is depicted in Fig. 4. The converged DG power is 45 MW and 30 MW for Cases 1 and 2, respectively showing the importance of the uncertainties in the system.

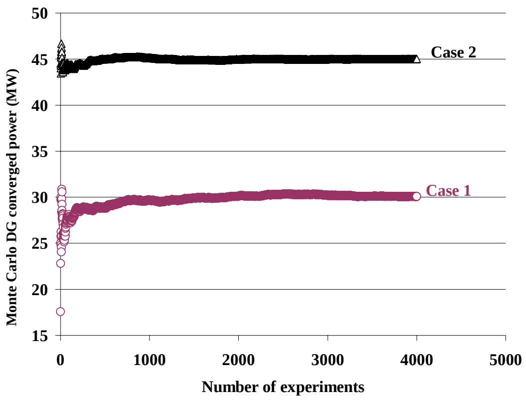

Fig. 4. Monte Carlo DG converged power for Cases 1 and 2.

The evaluated indices for three cases are presented in Table 3. As it is tabulated, for Base case, when all DG units are operating with their full capacities, the improvement in voltage profile, the reduction in losses, and the improvement in voltage stability are 21.8%, 14.65% and 29.23%, respectively. A comparison between Cases 1 and 2 with Base case shows that as number of uncertainties in the system increases the percentage of improvement in evaluated indices reduces. The percentage of voltage profile improvement in Cases 1 and 2 is 11.73% and 16.3%, while for the line loss reduction is 13.35% and 17.71%, respectively. It is worth mentioning that loadability margin is more sensitive to uncertainties involved in the system in comparison to the voltage profile and losses indices, where the percentage of improvement in loadability margin is 15.07% and 25.24% for Cases 1 and 2, respectively.

Table 3: Evaluated indices for simultaneous DG operation considering uncertainties in state and power generation.

Cases	VPII	LLRI	VSMI
Case1- Uncertainty in State and power generation	1.1173	0.8657	1.1507
Case 2- Uncertainty in Power Generation	1.163	0.8229	1.2524
Base case-Buses 29,26, and 30 with full capacity	1.218	0.8535	1.2923

CONCLUSIONS

The research shows that the loadability margin varies with type of DG and its reactive power support where synchronous generator units compared to asynchronous units have a large impact on the voltage stability margin. From the study of individual and simultaneous synchronous DG units operating in voltage control mode, it is concluded that integration of this type of DG unit enhances the loadability of the distribution system depending on DG location and to some extent its capacity. The obtained results demonstrate how the uncertainties involved with customer-owned DG units can affect the overall performance of the distribution system specially loadability margin.

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