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The Effects of Distributed Generation Sources within Commercial Retail Reticulation Networks

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Abstract

Distributed Generation (DG) systems are becoming more common with increasing electricity prices and growing awareness of sustainable energy generation sources. Reticulation networks are typically planned, designed and operated to be purely passive networks that deliver electricity to consumers in a unidirectional manner (from source to load). The integration of DG into reticulation networks can alter conventional power flow within the network, as well as load parameters. The effects of DG on load and network parameters is investigated in this paper through the use of a developed hypothetical commercial reticulation network and load demand profiles. The introduction of a DG source at low levels of penetration was found to not significantly alter load parameters, although effects are noticeable. The largest variation in load parameters can be observed at high levels of DG penetration. Since load parameters (such as coincident demand) play an important role in the design of reticulation networks, the results obtained from this study indicate that current design procedures and standards for reticulation networks must be scrutinized when high levels of DG penetration are introduced.

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Keywords: Distributed generation; load parameters; photovoltaic systems, reticulation network, wind power system.

1. Introduction

Renewable energy DG sources reduce carbon emissions as well as the dependence on fossil fuels to generate electricity. Another factor that has contributed to the increased utilization of renewable energy DG is the decreasing cost of electricity generation from renewable energy generation sources, such as wind and photovoltaic (PV) systems, as a result of the progression of technology [1]. Distribution networks in the past were traditionally planned, designed and operated to be purely passive networks that deliver electricity to consumers in a unidirectional manner with

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minimal, or no, monitoring and control capabilities [2]. In recent times the integration of DG into distribution networks has altered conventional power flow within the network resulting in bi-directional power flow which can impact load and network parameters [3].

It is important to understand the effects DG has on load and network parameters, and if existing reticulation network design procedures and standards are suitable for the design of reticulation networks that will contain varying levels of DG penetration. Although the body of knowledge related to the integration of DG into distribution networks is vast, there is little research related to the design of reticulation networks with specific attention paid to DG.

The key focus of this research is how DG effects load parameters when integrated into commercial retail reticulation networks. The load parameters that are investigated are load demand, coincident demand, demand factor, utilization factor, load factor, diversity factor, coincidence factor, load diversity, and loss factor. Factors that impact the technical performance of an electrical network are power losses, voltage regulation, equipment loading and utilisation, fault levels, stability limits, frequency and harmonics [4]. However, at a commercial retail reticulation network level, only certain network parameters are applicable and should be investigated. These parameters include the thermal rating of electrical equipment, reserve power flow capabilities of transformer tap-changes, steady-state voltage rise, and power losses. Supply voltage is regulated by electricity supply standards and national regulations; and is an important network parameter. It is for this reason that supply voltage was the only network parameter investigated in this paper. Load and network parameters for the reticulation network with no DG integrated are determined which forms the basis on which comparisons are made. DG, in the form of PV, was integrated into the reticulation network and penetration levels varied to investigate the effects of DG on load and network parameters.

2. Hypothetical Network Model

A hypothetical reticulation network is developed in this paper to investigate the effect of DG on load and network parameters. The load demand profiles are based on publically available load demand information [5]. Certain assumptions regarding network component capacities and sizes, as well as network topology, are made. The hypothetical reticulation network consists of five low-voltage loads that are supplied from a common step-down transformer. A load demand profile for each customer is developed. All profiles are assumed to be similar due to all customers being commercial retail electricity consumers. Maximum load demand and the length of the feeder cables to each of the customers are considered to be different in order to add variability to the network model. Commercial electricity consumers are modelled as voltage dependent loads [6]. A single line diagram (SLD) of the network outlining the topology and main components are shown in Fig. 1.

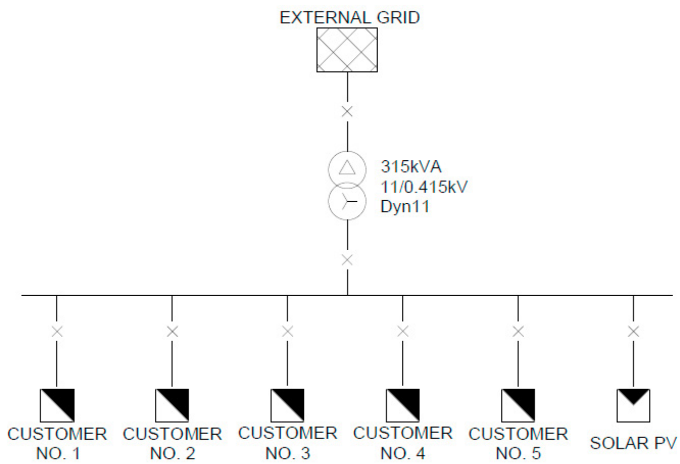

Fig. 1: Commercial retail reticulation network single line diagram

The network is modelled and simulated in DIgSILENT Power Factory to determine specific load and network parameters. The results are used to assess the effects and impact of integrating DG into networks. The load parameters were determined by post processing of results and network parameters that were obtained directly from DIgSILENT Power Factory.

3. Results and Discussion with Integration of DG

To determine the effect of integrating DG in terms of load and network parameters, a DG source is integrated into the commercial retail reticulation network model as shown in Fig. 1. The DG source capacity is varied to determine the effect that varying penetration levels has on load and network parameters. The DG source is connected to the main low-voltage busbar, which is common to all the customer feeders, as seen in Fig. 1. The DG penetration was based on a percentage of maximum load demand (167 kW). The DG penetration levels simulated are indicated by It should be noted that the capacity of the PV system modelled within the reticulation network is based on the percentage penetration, and are not practically achievable capacities.

Table 1. It should be noted that the capacity of the PV system modelled within the reticulation network is based on the percentage penetration, and are not practically achievable capacities.

Table 1: PV penetration levels and capacities modelled

Penetration	PV Capacity (kW_{ac})
10%	16.70
15%	25.05
20%	33.40
25%	41.75
50%	83.50
75%	125.25
100%	167.00

3.1. Load Parameters

Using the base case network model a PV DG source, with varying capacity, is integrated into the reticulation network. As can be seen from Fig. 2, low penetration levels of DG do not significantly alter the load demand profile while at high levels of penetration the load demand profile is significantly altered. The maximum load demand of 167kW for base case scenario (0% DG penetration) as shown in Fig. 2 occurs around 14:00. The integration of high levels of DG penetration can be seen to reduce the mid-day maximum load demand, which then shifts the maximum demand to later in the day. This is due to the PV generation output peaking around mid-day. This results in a lower maximum load demand for the total load.

Table 2 outlines the results obtained for the different load parameters for each DG penetration level simulated. From Table 2 it can be seen that the coincident demand decreases with the increase in DG penetration. Load diversity, on the other hand, increases with the increase in DG penetration.

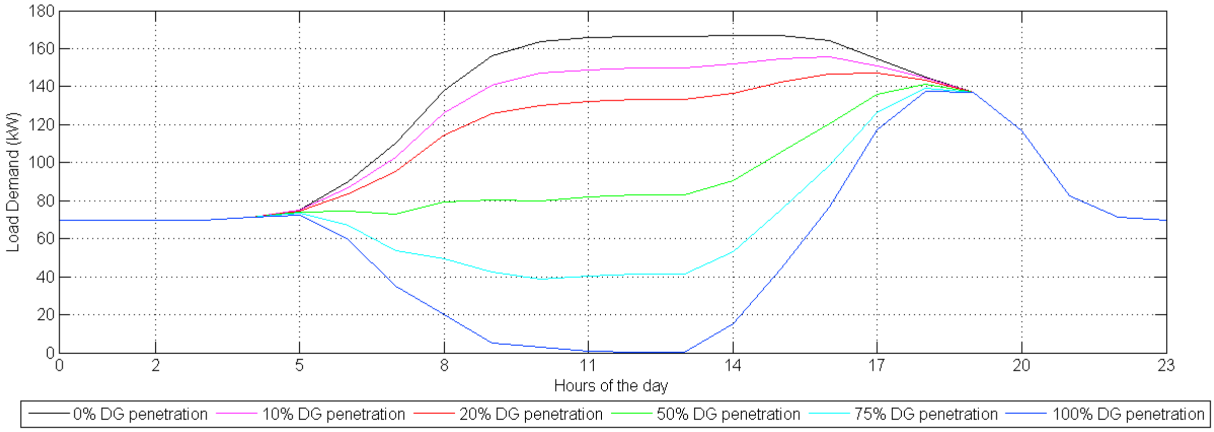

Fig. 2: Coincident load demand profile versus DG penetration

Table 2: Load Parameter results for varying levels of DG penetration

% DG Penetration	Load Parameter							
	Coincident demand (kW)	Demand factor	Utilisation factor	Load factor	Diversity factor	Coincidence factor	Load diversity (kW)	Loss factor
0	167.0	0.73	0.56	0.7131	1.02	0.98	3.92	0.540
10	155.5	0.68	0.53	0.7269	1.10	0.91	15.42	0.559
15	151.2	0.66	0.51	0.7275	1.13	0.88	19.72	0.560
20	147.2	0.64	0.50	0.7266	1.16	0.86	23.72	0.559
25	145.3	0.63	0.49	0.7152	1.18	0.85	25.62	0.543
50	141.2	0.61	0.48	0.6287	1.21	0.83	29.72	0.432
75	139.2	0.61	0.47	0.5292	1.23	0.81	31.72	0.319
100	137.3	0.60	0.47	0.4294	1.24	0.80	33.62	0.223

The integration of a DG source at low levels of penetration does not significantly alter load parameters, although the effect is noticeable. The largest variation in load parameters is at higher levels of DG penetration. The coincident demand decreases with an increase in DG penetration. This is due to the PV DG source supplying a portion of the load demand requirement, and any shortfall is then supplemented from the external grid. The coincident demand varies from 167kW to 137.3kW at 0% and 100% DG penetration respectively. Not only does the integration of a PV DG source reduces the maximum coincident demand, but also the time of day at which the maximum coincident demand occurs shifted from 14:00 in the day to around 18:30 in the evening.

The demand factor is also noted to decrease with an increase in DG penetration. This is due to the decrease in maximum coincident demand. The demand factor decreased from 0.73 to 0.60 at 0% and 100% DG penetration respectively.

Utilization factor also decreases with an increase in DG penetration. The utilisation factor of the step-down transformer decreased from 0.56 to 0.47 at 0% and 100% DG penetration respectively. This indicates that the step-down transformer is less loaded with the increase of DG penetration, and this is a function of where the DG source was connected in the reticulation network.

The load factor increases with DG penetration between 0% and 15%, and then decreases thereafter for DG penetration levels from 20% to 100%. The increase in load factor is related to the flattening of the load demand profile for a longer time period before the maximum coincident demand occurs. This results in a higher ratio of coincident demand to average load demand. The increase in load factor indicates a more stable load demand profile. As the DG penetration levels increase, the load demand profile starts to exhibit higher peaks and lower troughs that result in the load factor decreasing.

Diversity factor increases from 1.02 to 1.24 for 0% and 100% DG penetration respectively. The increase in diversity factor indicates that there is a larger variation between the maximum non-coincident demand and maximum coincident demand. The coincidence factor, being the inverse of diversity factor, decreases from 0.98 at 0% DG penetration to

0.80 at 100% DG penetration. The load diversity increases from 3.92kW at 0% DG penetration to 33.62kW at 100% DG penetration. The increase in load diversity is also related to the increase in diversity factor. Loss factor, being a function of load factor, varies in the same manner. Loss factor increases with DG penetration levels between 0% and 15%, and then decreases for DG penetration levels from 20% to 100%.

3.2. Network Parameter Results

Supply voltage varies inversely to load demand, this is due to the higher current drawn by the system at peak demand periods. Higher load currents drawn by the system results in a greater voltage drop. This results in the minimum supply voltage occurring at the same point in time as the maximum load demand. The variation of supply voltage as a function of DG penetration can be seen in Fig. 3. It is shown that the integration of high levels of DG penetration slightly improved the supply voltage profile.

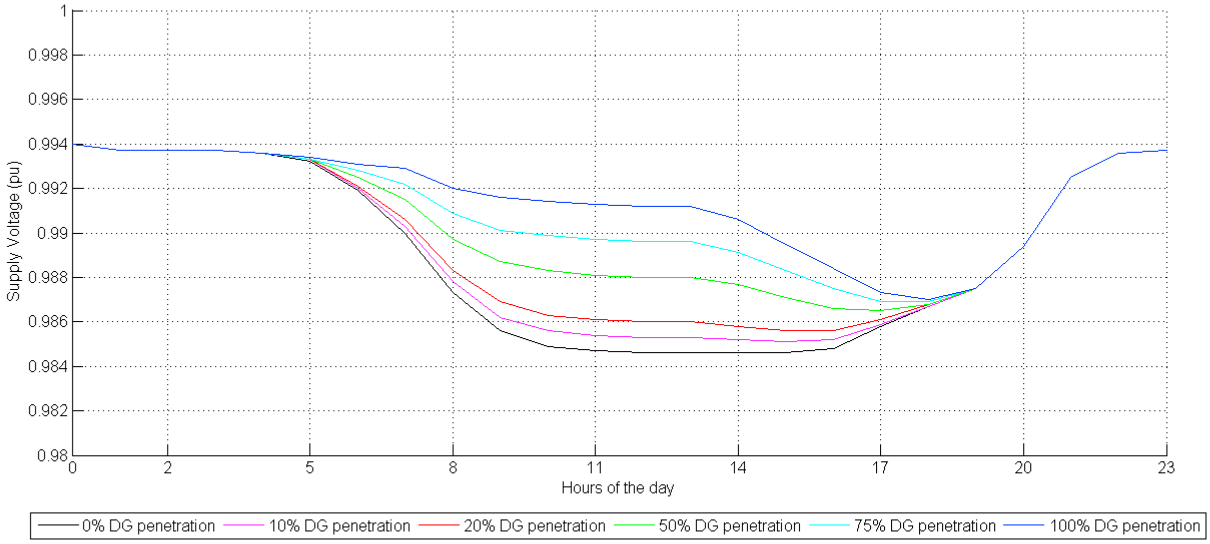

Fig. 3: Supply voltage profile versus DG penetration

The variation in the maximum and minimum supply voltage for each of the DG penetration levels modelled can be seen in Table 3. The introduction of the DG source only had an effect on the minimum supply voltages. The minimum voltages were seen to increase as the level of DG penetration increased. This is due to the lower load current drawn by the system. These minimums were observed during peak demand periods. The maximum supply voltages were not influenced by the introduction of DG

Table 3: Supply voltage maximum and minimum level for varying levels of DG penetration

	Supply Voltage (per unit)	
% Penetration	Minimum Voltage	Maximum Voltage
0	0.985	0.994
10	0.985	0.994
15	0.985	0.994
20	0.985	0.994
25	0.983	0.993
50	0.987	0.994
75	0.987	0.994
100	0.987	0.994

4. Conclusion

From the results it is seen that the introduction of high levels of DG penetration into a commercial retail network can significantly alter load parameters as seen by the external network. Load parameters (such as coincident demand) play an important role in the design of reticulation networks and selection of network components. The results obtained from the hypothetical study indicate that, due to the significant altering of certain load parameters, there is a need to assess the suitability of current design procedures and standards for reticulation networks proposed to contain high levels of DG penetration.

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Biography

Prof. Ramesh Bansal has over 25 years of experience and currently he is a Professor and group head (Power) in the Department of EEC Engineering at University of Pretoria. He has published over 250 papers. Prof. Bansal is an Editor of IET-RPG & Electric Power Components and Systems. He is a Fellow and CEng IET-UK, Fellow Engineers Australia and Institution of Engineers (India) and Senior Member-IEEE.