A CASE FOR NEW DESIGN METHODOLOGIES FOR DISTRIBUTION NETWORKS

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1. Introduction

The installed capacity of solar photovoltaic (PV) generation sources around the world increased by 50% for 2017 [1].The main factor that has contributed to the increased utilization of renewable energy distributed generation (DG) is the decreasing cost of electricity generation from renewable energy generation sources, such as solar PV systems, as a result of the progression of its technology [2]. Within South Africa approximately 58% of the installed solar PV capacity is within the commercial sector [3].

Distribution networks are typically planned, designed and operated to be purely passive networks that deliver electricity to consumers in a unidirectional manner with minimal, or no, monitoring and control capabilities [4]. Networks are planned and designed on the "fit and forget" principle [5], which implies that minimal management of the distribution network is required. In recent times, the integration of DG into distribution networks has altered conventional power flow within the networks resulting in bi-directional power flow, which can impact load and network parameters [6]. Distribution networks therefore need to be able to respond to such changes and in addition, network planners and designers need to develop distribution networks that are fit for serving future electricity consumers.

It is important to understand the effects DG has on load parameters, as these parameters influence the planning and design of distribution networks that contain varying levels of DG penetration.

The key focus of this research was how DG effects load parameters when integrated into a commercial retail reticulation network, as seen by the distribution network. The load parameters that were investigated are coincident load demand, demand factor, utilisation factor, load factor, diversity factor, coincidence factor, load diversity, and loss factor. Two different integration locations, within the commercial reticulation network, were investigated (central and de-central) including varying capacities.

2. Case study

A case study was developed to understand the effects of DG on load parameters for commercial retail facilities, as this is where majority of the solar PV systems are installed. The study was based on an existing commercial retail park situated in Pretoria, South Africa. To accurately develop a network model, along with the load demands for each of the electricity customers, certain information was required. The information required was metered load demand data for each of the customers within the reticulation network as well as equipment ratings, capacities, size and configuration of the reticulation network in use. Section 2.1 and 2.2 provide further details on the information gathered to develop the network model for the case study.

2.1 Load modelling

To develop representative load models for each of the customers within the reticulation network, recorded load demand information such as electricity demand, energy consumption and power factor over time was required. Within the commercial retail facility there are a total of 40 electricity consumers.

The measured load data obtained was analysed to determine an average half-hourly load demand profile for each customer. This result was then used as the input to the load model for the customer within the DIgSILENT network model, used for power flow analysis. In addition to the average load demand profile for each customer input to the DIgSILENT model, an average half-hourly power factor profile over the same period of operation was also used as an input.

Two different months (January and July) of measured load demand data were used to also understand the impact of seasonal variation in load demand and solar PV generation on load parameters, as seen by the distribution network.

2.2 Reticulation network

A single line diagram of the reticulation network is given in Figure 1 and provides an overview of the reticulation network topology servicing the commercial retail facility. Details of the reticulation network were determined from an on-site inspection of the facility. For some of the network components the information was not visible on-site and assumptions had to be made, such as the capacity of the main transformer supplying the facility.

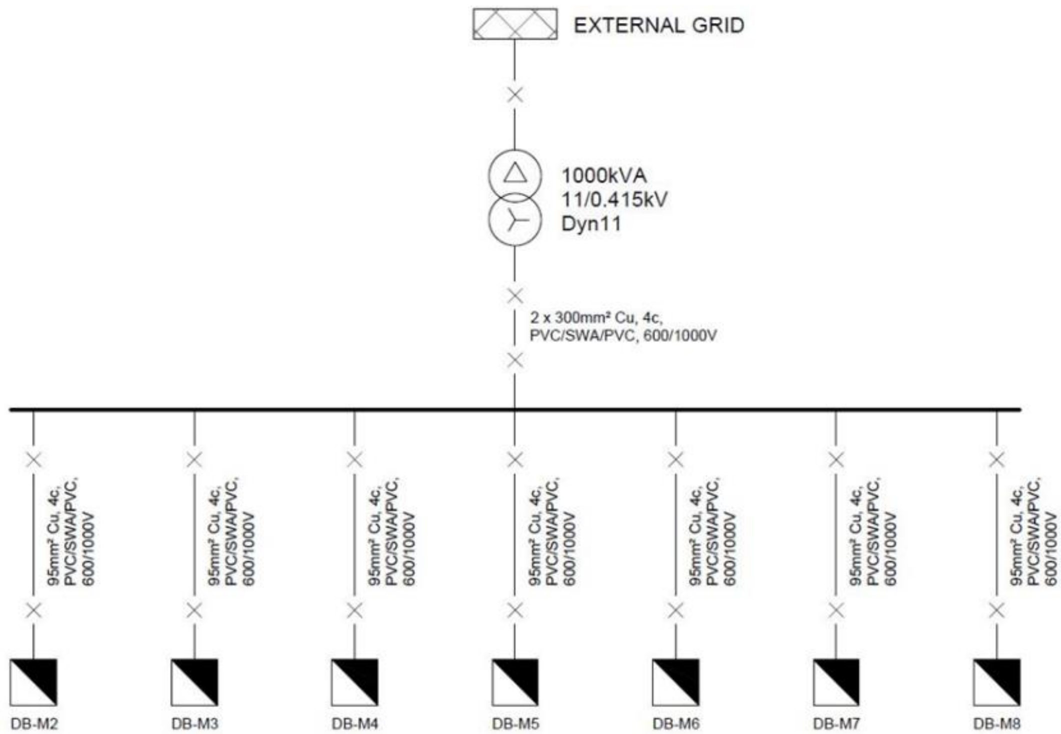

Figure 1: Commercial facility reticulation network single line diagram

2.3 Centralised DG scenario results

To determine the effect on load parameters from the introduction of a solar PV DG source, the first scenario that was investigated was to integrate the DG source centrally within the reticulation network. The DG source was modelled as being connected to the main low-voltage distribution board supplying each of the sub-distribution boards, as this is the central location of the network.

2.3.1 January 2017 load demand scenario

The impact of DG on the load demand profile for the January 2017 load demand scenario is given in Figure 2. The base case, (blue dashed line) shown in Figure 2, is the coincident load demand of the facility without any DG source present. The solar PV DG source capacity modelled for each percentage load penetration was a percentage of the maximum coincident demand for the base case. For this scenario, the maximum coincident demand was approximately 110kW.

The variation of each of the load parameters, under investigation, for the different DG penetration levels is given in Table 1. From the results obtained it can be seen the load parameters that are the most significantly impacted are coincident demand, transformer capacity percentage utilisation, diversity factor, coincidence factor and load diversity.

From Figure 2 it can be seen that the maximum coincident demand is shifted to occur later in the day compared to the base case. This is due to the overlap between the load demand profile and the solar PV generation profile.

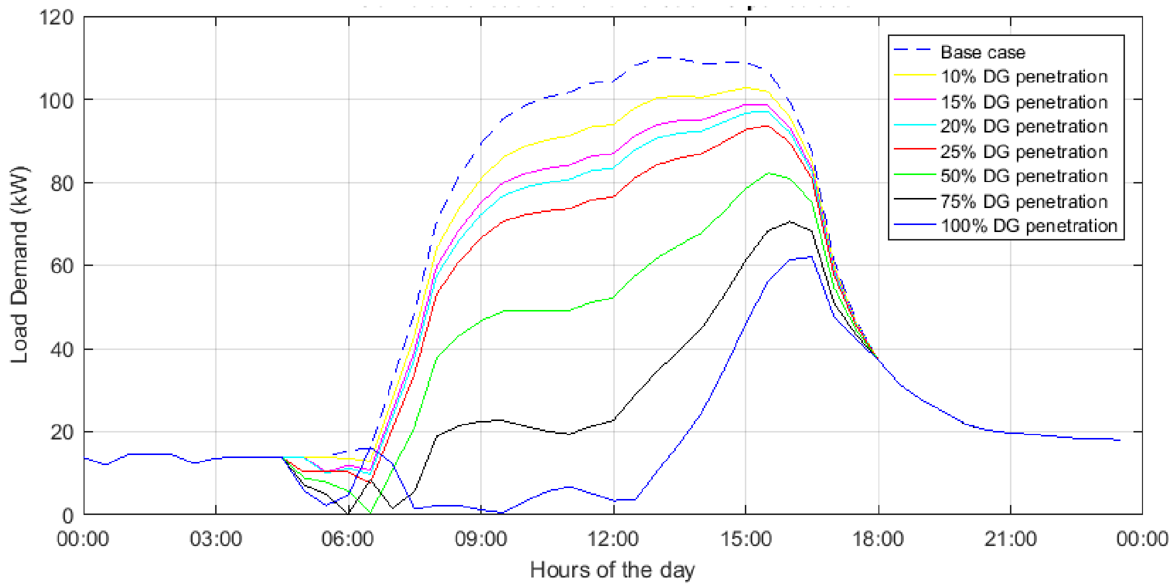

Figure 2: Coincident load demand versus DG penetration (January 2017 load demand scenario)

Table 1: Load parameters versus percentage DG penetration (January 2017 load demand)

	Load parameter							
%	Coincident demand	Demand factor	Utilisation factor	Load factor	Diversity factor	Coincidence factor	Load diversity	Loss factor
0	109.92	0.068	14.02	0.465	1.097	0.912	10.61	0.255
10	102.79	0.063	13.42	0.464	1.173	0.853	17.73	0.254
15	98.73	0.061	13.09	0.460	1.221	0.819	21.79	0.250
20	96.91	0.060	12.94	0.457	1.244	0.804	23.61	0.247
25	93.64	0.058	12.63	0.448	1.287	0.777	26.89	0.239
50	82.18	0.051	11.59	0.414	1.467	0.682	38.34	0.209
75	70.52	0.044	10.35	0.352	1.709	0.585	50.01	0.160
100	62.04	0.038	7.72	0.299	1.943	0.515	58.49	0.122

2.3.2 July 2016 load demand scenario

The impact of DG on the load demand profile for the July 2016 load demand scenario is given in Figure 3. The solar PV DG source capacity modelled for each percentage load penetration was a percentage of the maximum coincident demand. For this scenario, the maximum coincident demand is approximately 137kW. From comparing Figure 2 and Figure 3, it can be noted the maximum coincident demand (for the base case) occurs earlier in day in the July 2016 load demand scenario than in the January 2017 load demand scenario. This would be attributed to the seasonal variation in load demand. The maximum load demand for this scenario was shifted from approximately 9:30 in the morning to approximately 16:30 in the afternoon, for the 100% DG penetration scenario.

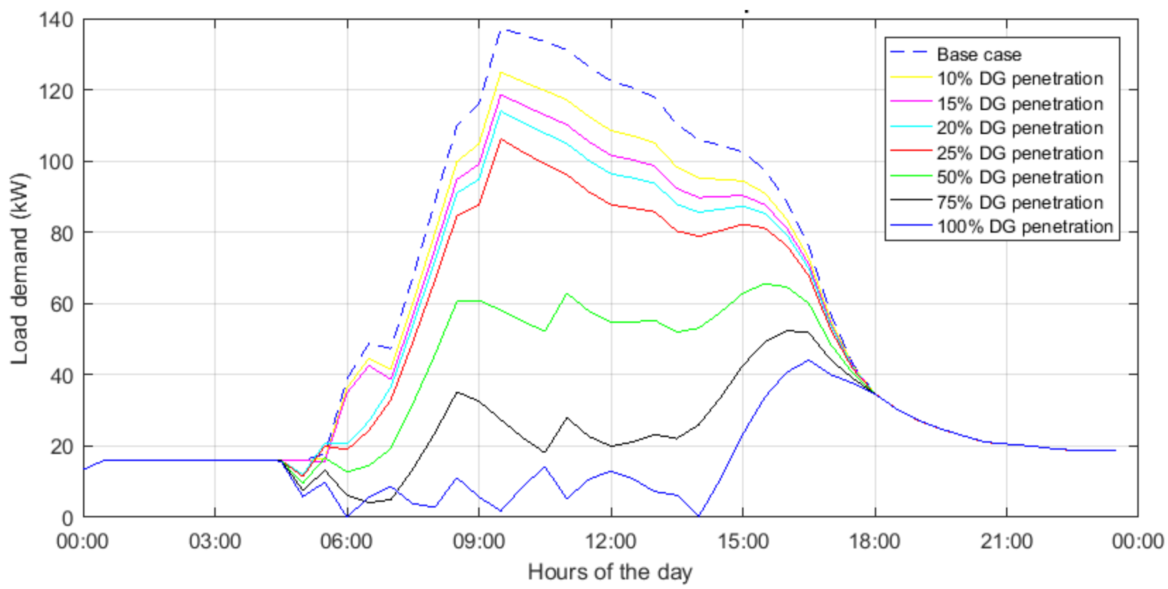

Figure 3: Coincident load demand versus DG penetration (July 2016 load demand scenario)

The variation of each of the load parameters, under investigation, for the different DG penetration levels is given in Table 2. From the results obtained it can be seen the load parameters that are most significantly impacted are coincident demand, transformer capacity percentage utilisation, diversity factor, coincidence factor and load diversity. These parameters are impacted more than in the January 2017 load demand scenario. This would be due to there being greater overlap between the solar PV generation profile and load demand profile.

Table 2: Load parameters versus percentage DG penetration (July 2016 load demand)

	Load parameter							
%	Coincident demand	Demand factor	Utilisation factor	Load factor	Diversity factor	Coincidence factor	Load diversity	Loss factor
0	137.27	0.085	18.51	0.424	1.360	0.735	49.41	0.218
10	124.89	0.077	17.29	0.430	1.495	0.669	61.78	0.223
15	118.67	0.073	16.67	0.434	1.573	0.636	68.00	0.226
20	113.99	0.070	16.22	0.432	1.638	0.611	72.68	0.225
25	106.21	0.066	15.48	0.437	1.758	0.569	80.47	0.229
50	65.57	0.040	12.55	0.528	2.847	0.351	121.10	0.318
75	52.36	0.032	9.74	0.446	3.565	0.280	134.31	0.237
100	44.12	0.027	8.52	0.377	4.231	0.236	142.56	0.178

2.4 De-centralised DG scenario results

Another possible scenario that was investigated was how load parameters would be altered from the integration of a solar PV DG source connected to a single customers' local distribution board, referred to as the de-central DG scenario. The DG source capacity was varied as a percentage of the maximum load demand at the selected sub-distribution board to which it was integrated. The effect on the composite load parameters were then to determine, as seen by the distribution network.

The DG source was modelled as being connected to sub-distribution board DB-M3, as shown in Figure 1. The reason DB-M3 was selected, was because this is the sub-distribution board with the highest load demand out of the seven. Sub-distribution board DB-M3 services five different customers. The solar PV DG source capacity modelled for each percentage level was a percentage of the maximum coincident demand. For this scenario, the maximum coincident demand is approximately 25kW at sub-distribution board DB-M3.

2.4.1 January 2017 load demand scenario

The impact of varying DG capacity on the load demand profile for the January 2017 scenario is given in Figure 4, for the de-central DG scenario.

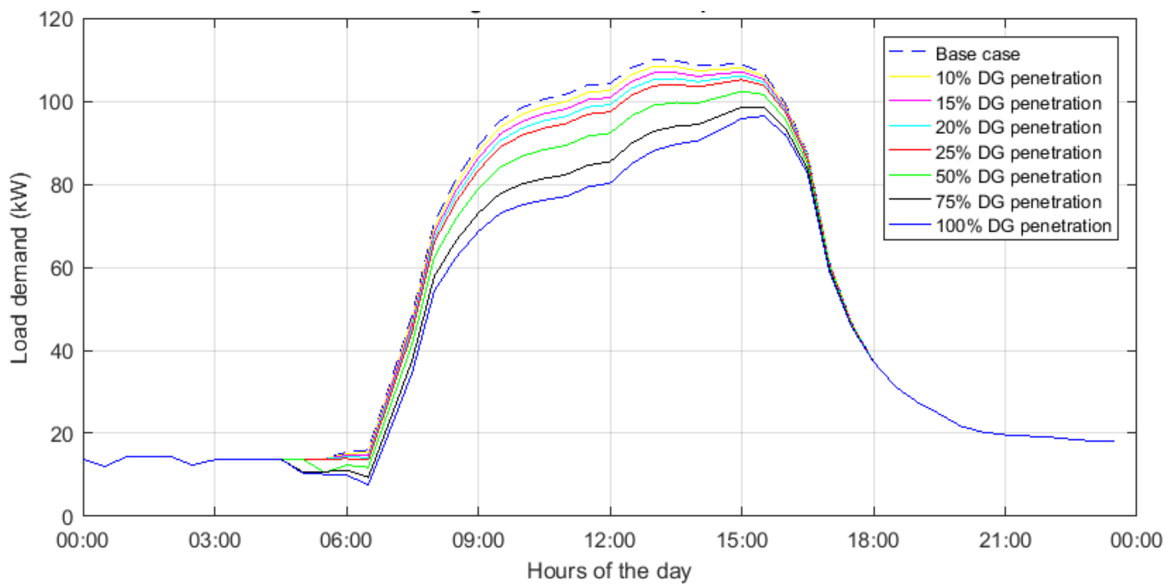

Figure 4: Coincident load demand versus DG penetration (January 2017 load demand scenario)

The variation of each of the load parameters for the different DG penetration levels is given in Table 3, for the de-central DG scenario. From the results obtained it can be seen the load parameters that were most impacted are coincident demand, diversity factor, coincidence factor and load diversity. It should be noted that the utilisation factor given in Table 3, is the percentage utilisation of the feeder cable supplying DB-M3. Load factor was noted to increase for low levels of DG penetration. This is an interesting result as there are benefits to having a higher load factor, as there is less of a variation in load demand.

From Figure 4 it can be seen that the maximum coincident demand was not shifted to later in the day, as noted for the central DG scenario. The load demand profile was not altered and this would be due to the reduced solar PV DG capacity integrated into the reticulation network. The maximum coincident demand was however reduced by approximately 12%, for this scenario.

Table 3: Load parameters versus percentage DG penetration (January 2017 load demand)

	Load parameter							
%	Coincident demand	Demand factor	Utilisation factor	Load factor	Diversity factor	Coincidence factor	Load diversity	Loss factor
0	109.92	0.068	14.02	0.465	1.097	0.912	10.610	0.255
10	108.35	0.067	13.90	0.466	1.112	0.899	12.171	0.256
15	107.01	0.066	13.82	0.467	1.126	0.888	13.514	0.257
20	106.08	0.065	13.73	0.466	1.136	0.880	14.451	0.256
25	105.14	0.065	13.64	0.465	1.146	0.872	15.388	0.254
50	102.33	0.063	13.38	0.460	1.178	0.849	18.197	0.250
75	98.62	0.061	13.09	0.454	1.222	0.818	21.909	0.245
100	96.40	0.059	12.89	0.447	1.250	0.800	24.121	0.238

2.4.2 July 2016 load demand scenario

The impact of varying DG penetration level on the load demand profile for the July 2016 load demand scenario is given in Figure 5, for the de-central DG scenario.

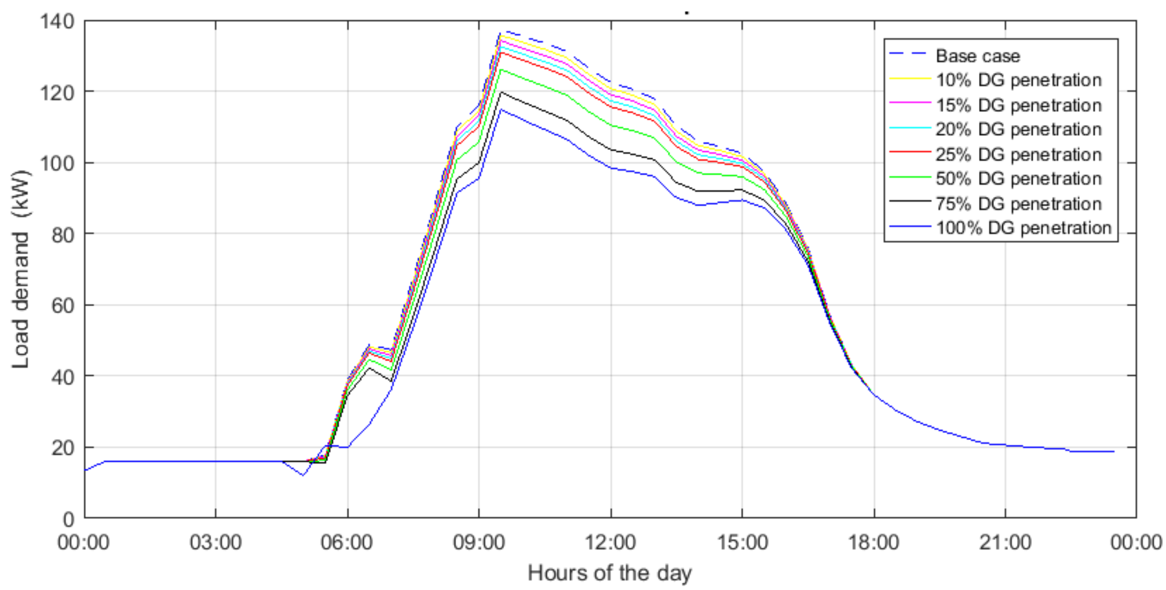

Figure 5: Coincident load demand versus DG penetration (July 2016 load demand scenario)

The variation of each of the load parameters for the different DG penetration levels is given in Table 4, for the de-central DG scenario. It can be seen the load parameters that were most impacted are coincident demand, diversity factor, coincidence factor and load diversity, as noted for the January 2017 load demand scenario.

From Figure 4 it can be seen that the maximum coincident demand was again not shifted to occur later in the day, as noted for the central DG scenario. The maximum coincident demand was however reduced by approximately 16%. This reduction is not significantly greater than the reduction noted in the January 2017 load demand scenario; however, it is larger. This indicates that there is more of an overlap between the solar PV DG generation profile and load demand profile, for the load demand scenario, as the DG source capacity was not altered.

Table 4: Load parameters versus percentage DG penetration (July 2016 load demand)

	Load parameter							
%	Coincident demand	Demand factor	Utilisation factor	Load factor	Diversity factor	Coincidence factor	Load diversity	Loss factor
0	137.27	0.085	18.506	0.424	1.109	0.902	14.98	0.218
10	135.67	0.084	18.349	0.425	1.122	0.891	16.57	0.219
15	134.14	0.083	18.208	0.426	1.135	0.881	18.10	0.219
20	132.52	0.082	18.048	0.427	1.149	0.870	19.72	0.220
25	130.91	0.081	17.889	0.428	1.163	0.860	21.33	0.221
50	126.11	0.078	17.415	0.431	1.207	0.828	26.13	0.224
75	119.73	0.074	16.790	0.435	1.272	0.786	32.52	0.227
100	114.95	0.071	16.306	0.433	1.324	0.755	37.29	0.226

3. Conclusion

With a worldwide focus on becoming more sustainable and environmentally conscious, the uptake of renewable energy DG sources is increasing. The studies conducted have proven that introducing DG into low-voltage networks, such as commercial retail reticulation networks, does affect the load parameters, as seen by the external distribution network. It is therefore imperative to understand what the effects of integrating DG are, to ensure that future network planning and design is done successfully, safely and effectively.

The most noticeable impact on load parameters was seen in the central DG scenario. This is due to the large DG system capacity integrated, which affects coincident demand more significantly when compared to the de-central DG scenario. The load demand profile is therefore impacted significantly (for the central DG scenario) and this results in the greatest variation in load parameters. A variation in load parameters was noted for the de-central DG scenario; however, due to the smaller installed system capacities the effect was not as large as for the central DG scenario.

Commercial retail reticulation networks typically form part of a larger power system. Understanding how load parameters are altered from the introduction of DG will aid in successful and efficient network planning and design that is done for distribution networks.

Coincident demand, diversity factor and load factor play an important role network planning and design. The results obtained indicate that there is a case to be made to re-assess the suitability of existing planning and design procedures or standards for distribution networks that will contain varying levels of DG penetration.

References

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