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Impacts of DG on Distribution Losses

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Abstract: This paper shows the results obtained in the analysis of the impact of distributed generation (DG) on distribution losses. The main objective has been to determine if DG whether increments or decrements distribution losses, based on the penetration level and dispersion of DG and on the different DG technologies. Different scenarios with several penetration levels and dispersion of DG have been studied. The special characteristics of different DG technologies have been taken into account. The considered technologies are: combined heat and power (CHP), wind turbines, photovoltaics and some theoretical ones. Real radial distribution feeders have been used.

Index Terms: Distributed generation (DG), Distribution, Losses.

I. INTRODUCTION

Nowadays the distributed generation (DG) is taking more relevance and it is anticipated that in the future it will have an important role in electric power systems. In Spain the technical term of distributed generation does not exist. Nevertheless, Spanish regulation recognises a special category of power producers called "Régimen especial". This category of producers includes the power stations smaller than 50 MW whose production comes from renewable energy sources, waste or combined heat and power (CHP). In 2001 the contribution in Spain of this kind of generation to total demand was of 14,8% [1]. It is anticipated that its participation will continue increasing. DG will have positive and negative impacts on distribution networks [2]. This impact affects aspect like losses, investments and power quality [3]. In Spain, all electrical consumers have a standard loss coefficient which depends on their tariff. These coefficients are set annually by the regulatory body. The distribution companies (DISCOs) buy in the pool the energy injected into their networks so they buy "real" losses.
The consumers pay to DISCOs the energy they consume times the standard loss coefficient. DISCOs buy "real" losses but they charge "standard" losses to their customers so they have an incentive to reduce losses [4]. As DG changes real distribution losses it will have direct impact in DISCOs' profit. If DG decrease "real" losses, DISCOs' profit will increase but if DG increase "real" losses their profit will decrease. This is a good reason to study the impact that this type of generation produces on distribution losses. The main objective of the study has been to quantify the impact (increase or decrease) that DG produces on losses on distribution networks considering several aspects.
These aspects are:
- *DG penetration level*: ratio of capacity factor times total DG power installed and the peak power demanded on the feeder.
- *DG dispersion*: ratio of number of nodes in which there is DG and the number of nodes in which consumption exists.
- *DG technologies*: the technologies considered are CHP, wind turbines, photovoltaics and some theoretical plants.
- *Generation mix*: this is related with different DG technologies in the same feeder. In section II the methodology used will be presented. Section III describes different models used. The results obtained will be presented in section IV.

II. METHODOLOGY

Annual losses variation due to DG in radial distribution networks is the objective of this study. To estimate such variation, some simplifications are needed. First of all, a collection of representative feeders of the radial distributions networks to be analysed has to be made. The results presented here were obtained from a single feeder representing dispersed rural feeders. Second, several scenarios are to be chosen to analyse the impact of DG. This scenarios will be described in next section. For each one of these scenarios, losses are analysed through load flow calculation (Newton-Raphson algorithm was used). This load flow calculation allow us to obtain active and reactive flows and their influence in total losses. Another explanatory variables like marginal loss coefficients, voltage profile, etc. can be obtained. Calculation of marginal loss coefficients was made using the same procedure used in [5]. In each scenario the penetration level is increased to see the behaviour of losses in the feeder. The purpose of this is to obtain total losses curve vs penetration level. This will give us information about which is the optimal DG penetration from losses point of view. The study has been made for a period of a year. To simplify the analysis, it was decided to split a year in several periods. For this reason it was chosen to calculate losses with time of use tariffs (TOUs) according to the effective tariffs in Spain [6]. Table 1 shows the periods of this TOUs.

Table 1. Time-of-use tariffs.

Period	Day type			
	Type A (hour)	Type B (hour)	Type C (hour)	Type D (hour)
1	16-22	-	-	-
2	8-16 22-24	-	-	-
3	-	9-15	-	-
4	-	8-9 15-24	-	-
5	-	-	8-24	-
6	0-8	0-8	0-8	0-24

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Days type *A* corresponds to working days of high season (November, December, January and February). Days type *B* correspond to working days of middle season (March, April, July and October). Days type *C* corresponds to working days of low season (May, June and September). Days type *D* corresponds to weekends, holidays and August. In order to be able to work with TOUs it is necessary to know for every period the average values of load demand and power output of DG. Once the losses are calculated for each period, the annual values are obtained using a weighed sum. The increase or decrease of losses was calculated as the difference in losses in the scenario in study and losses in the base case (feeder without DG).

III. MODELLING

This section describes the models that were used.

A. Modelling of networks

Modelling of networks is based on topology data of real medium voltage networks. R + jX modelling was used for all cables using real data. Capacitors, reactances, and other devices have not been considered. The slack node is the feeder header. The effect of feeders connected to the same bus bar has not been considered. Results presented in this paper correspond to a 20 kV rural feeder with 61 nodes (see Appendix).

B. Modelling of load demand

Modelling of load is based on historical data of consumption corresponding to each type of tariff. These historical data correspond to hourly values. With these hourly values, the averages values for every period were obtained. In each node the number of consumers is known as well as the type of contracted tariff so is possible to know at every moment the load demand in each node. Load nodes are considered as a PQ node with $\cos\varphi = 0.95$ in average. They are modelled as constant power load, that is, independent of voltage level. This has been considered irrelevant at this stage of the study.

C. Modelling of DG

The modelling of DG has considered the own characteristics of each technology. The following technologies have been modelled: CHP, wind turbines, photovoltaics and other schemes that, although theoretical, are interesting to study.

1) CHP: In order to define the production profile of CHP plants real annual hourly data have been used. These data are the energy supplied by these plants to MV networks. In Spain this kind of plants use net metering. Once the annual hourly values are obtained, the averages values for every period are obtained.

2) Wind turbines: To consider the stochastic nature of wind speed a very simple model has been used. For each hour a random number is generated with a Rayleigh's probability density function with mean equal to the average speed of the wind farm's location. A wind farm is simulated as only one wind turbine. The correlation of wind turbines in the same wind farm has not been considered. Once the hourly value of wind is obtained, the power curves of wind turbines are used to obtain the value of theoretical power available. Once the hourly values are obtained it is possible to calculate the averages values corresponding to every period.

3) Photovoltaics: In order to model this type of plants, the variation of solar radiation has been considered. This variation is due to the passage and rotation movements throughout the year. The model also considers the characteristics of the location (latitude, longitude, etc.). With these data, theoretical values of extraterrestrial radiation are obtained. In order to obtain the values of radiation that reaches the terrestrial surface is necessary to use local correction factors to consider the effect of clouds. Once the annual values of radiation have been obtained it is possible to obtain the power produced by installation using the characteristics provided by the manufacturers of solar cell arrays. With the annual hourly values the average values for every period are obtained.

4) Other plants: Other theoretical generation plants were considered. The first one is a DG that is able to exactly follow the profile of consumption on the feeder. That is, the production profile of these scheme is exactly the same as the profile of consumption on the feeder. The second one is a type of DG plant that produces each hour at full load. This type of plants have a flat profile so the average values for every period are constant. Another important issue is the type of reactive control. For all DG technologies the possibility of supplying reactive power has also been analysed to quantify the impact on losses. This possibility depends on the technology of DG and so DG cannot supply reactive power in all the cases. For instance, CHP plant with synchronous generators can provide reactive power. DG technologies with power electronic interface based on self commutated converters (typically based on IGBT devices) can be operated at any desired power factor [7]. Example of this type of DG are photovoltaics and wind turbines with AC-DC-AC converters. Some interesting conclusions will be presented.

D. Scenarios

As presented earlier, several scenarios have been studied. For each one, the penetration level has been increase from 0 % (base case) to 30 - 100 %, depending on the chosen scenario. The penetration has been measured by the ratio of capacity factor times total DG power installed and the peak power demanded in the feeder.

Penetration level = capacity factor × DG power installed/peak power (1)

The following table shows the capacity factor used for each technology. These capacity factors have been calculated with the average values obtained for each period. For this reason these capacity factors not correspond with real capacity factor of each technology.

Table 2. Capacity factor.

Technology	Hours	Capacity factor (%)
Full load	8760	100
Profile	5536	63.2
CHP	4581	52.3
Photovoltaics	1130	12.9
Wind turbines	919	10.5

The different scenarios are combination of the following:

• DG dispersion: It was measured by the ratio of number of nodes in which there is DG and the number of nodes in which consumption exists. The main scenarios of dispersion that have been modelled are the following:

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1) “Ideal” scenario: In this scenario DG was installed in each node in which demand exists. The power of DG installed in each node is proportional to the load demanded in this node.
2) “Semi-ideal” scenario: In this scenario DG was installed only in half of the nodes in which demand exist. The power of DG installed in each node is proportional to the load demanded in this node.
3) “3, 2 and 1 DG” scenarios: In these scenarios DG was installed in 3, 2 or 1 nodes. The location of DG was decided deterministically. The power of GD installed in each node is the same in each node.
• Generation mix: The scenarios also have considered different type of generation to analyse the influence of each DG technology. A “*realistic*” mix of DG has been used.

IV. RESULTS

In this section the relevant results will be presented. The results correspond to a 20 kV rural feeder with 61 nodes (see Appendix). Figure 1 shows the behaviour of losses for the “ideal” dispersion scenario for all DG technologies and DGs’ nodes modelled as a PQ nodes.

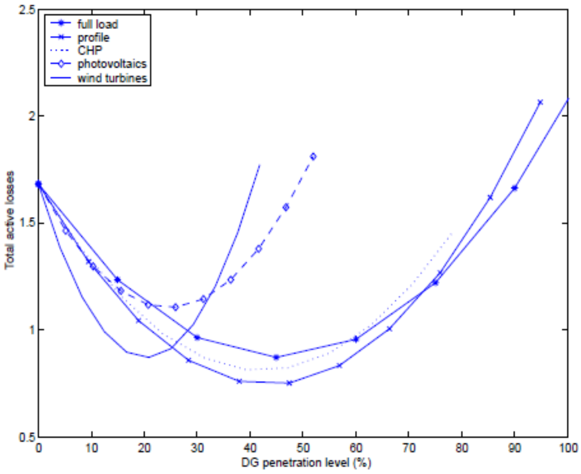

Figure 1. Total losses.

The previous figure shows that the better result is obtained with “*profile*” generation. It can see that with wind turbines, losses begin to marginally increase for a low penetration level. This behaviour is due that with the same DG penetration level the energy injected by wind turbines have a high variability. Figure 2 shows the results for the “3 DG” scenario with DG in nodes 17, 42 and 58.

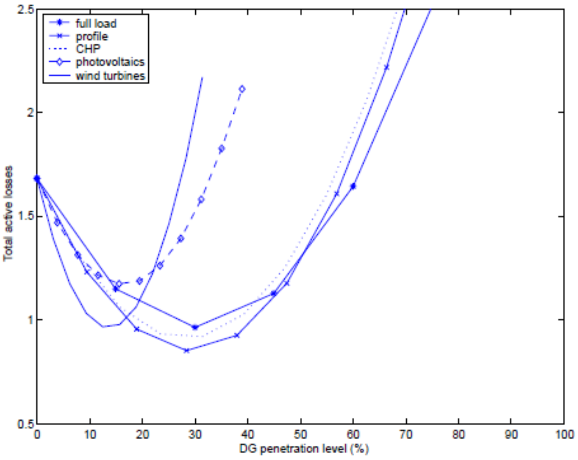

Figure 2. “3 DG” scenario

In the “3 DG” scenario losses decrease less than in the “ideal” scenario. Figure 3 shows the results for 1 DG scenario with DG in node 47. In this scenario losses decrease less than in the “3 DG” scenario. The purpose of “3 DGs”, “2 DGs” and “1 DG” scenarios is to assess the behaviour of total losses with DG spread out in different places in the feeder. Marginal loss coefficient is a variable that explain the influence of each node to total losses. Figure 4 shows marginal loss coefficients for different DG penetration levels and 3 DG scenario. Each graph corresponds to a penetration level. The last one correspond to 0% and the others to successive increases of 8% until reaching the value of 80% (first graph)

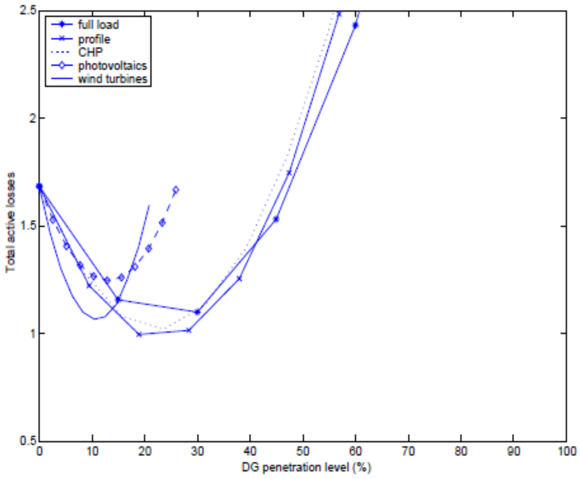

Figure 3. “1 DG” scenario

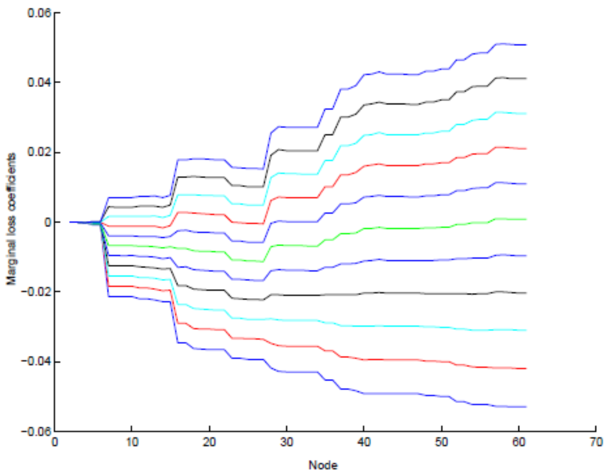

Figure 4. Marginal loss coefficients.

The negatives values in the previous figure means than in these nodes power injection decreases losses whereas positive values means that power injection increases losses. The nodes that are far away from the head feeder have a bigger impact on marginal losses due to the radial characteristics of the feeder. 3 DG scenario, have a balanced behaviour, that is, 3 DGs placed appropriately cause a smooth marginal loss coefficients profile. An interesting result can be extract with the analysis of PV and PQ nodes. Figure 5 shows the effect to model DGs’ nodes as PV or PQ nodes.

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When DGs' nodes are modelled as PV nodes the voltage set point was the voltage at this node in base case plus 5%. This set point is referred to the 20 kV voltage side. The maximum reactive power that DG can supply or consume was controlled with cosφ = 0.8.

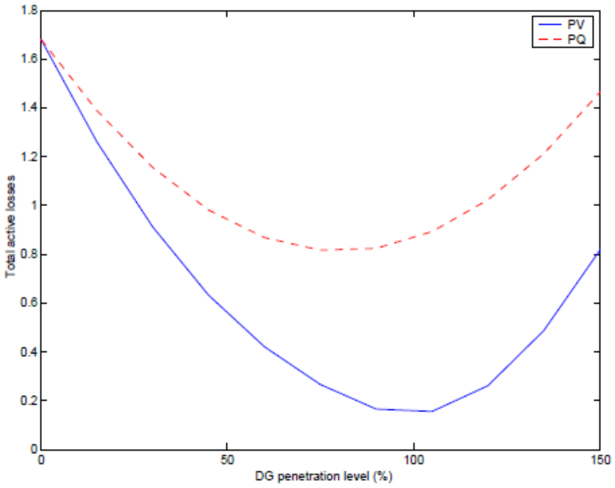

Figure 5. Comparison of DG nodes (PQ or PV)

The previous figure shows that if DG can control reactive power supplied (PV node) total losses decrease more than if DG cannot control reactive power supplied (PQ node). This simultaneously allows that the degree of penetration of DG increases before the losses marginally increase again. At present, utilities deal with DG as node PQ fixing to them cosφ = 1. This unables taking advantage of the maximum positive impact than DG can have if they were controlled on an active way. It is necessary to consider that the possibility toprovide reactive power depends on the technology of DG and so DG cannot be treated as a PV nodes in all the cases Ideally, reactive power supplied by DG should be controlled instantaneously to decrease losses but this requires a sophisticated control. Nevertheless, a simplified strategy can be adopted. For instance, it is possible to set different cosφ to DG for each TOU's period. This scheme needs a particular study for each distribution feeder and it can be introduced easily with effective TOUs tariffs.

V. CONCLUSIONS

Several conclusions can be extracted for this study: Losses variation on distribution networks due to DG have a sort of "*bathtub curve*" behaviour. In general, for low DG penetration level, losses decrease but for higher penetration level losses marginally increase and even can be higher than losses in base case. Minimum losses levels are reached with high penetration levels if DG is sufficiently dispersed. Controlling reactive power supplied by DG have a big impact on distribution losses. This need a sophisticated control but a simple scheme can be implemented. In a competitive system it will be necessary that the DGs receives the suitable economic signal so that they are interested in supplying reactive power to the network. Nodes that are far away from header in radial networks have a bigger impact on marginal loss coefficient and so in losses. With 3 DGs placed appropriately the feeder has a balanced behaviour. That is, 3 DGs placed appropriately cause a smooth marginal loss coefficients profile.

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AUTHOR PROFILE

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VIII. APPENDIX

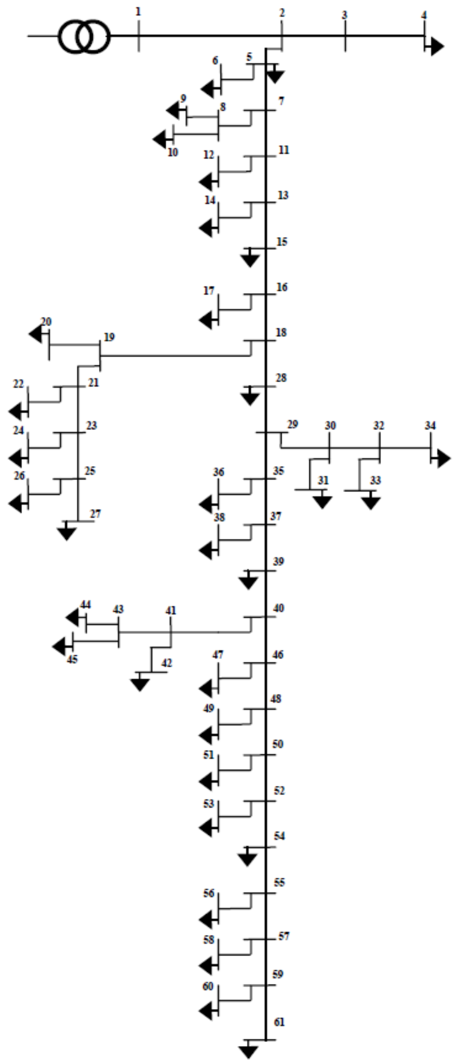

Figure 6. Rural distribution feeder analysed.

Table 3. Basic data

Total Costumers	4014
Total Load (MVA)	10.9
Peak load (MW)	1,52
Total Length (km)	58,8

In Table 3 load refers to load installed in the feeder peak load was calculated using the procedure described in modelling of load demand.

Table 4. Feeder data

	Costumer data		Line data	
Ending node	Costumers	Load (kVA)	Impedance (Ω/km)	Length (km)
2	0	0	0,614+j0,393	0,506
3	0	0	0,89+j0,13	0,011
4	378	630	0,89+j0,13	0,335
5	7	108,9	0,614+j0,393	0,26
6	1	73,3	0,9+j0,11	0,26
7	0	0	0,614+j0,393	6,672
8	0	0	0,614+j0,393	0,128
9	1	250	0,614+j0,393	0,04
10	1	6,6	0,614+j0,393	0,067
11	0	0	0,614+j0,393	0,238
12	177	516,9	0,25+j0,1	0,245
13	0	0	0,614+j0,393	0,115
14	490	1422,02	0,614+j0,393	1,128
15	317	816,15	0,614+j0,393	0,182
16	0	0	0,614+j0,393	5,279
17	1	0	1,074+j0,4	0,029
18	0	0	0,614+j0,393	0,725
19	0	0	0,614+j0,393	0,118
20	552	1506,77	0,614+j0,393	0,286
21	0	0	0,614+j0,393	0,441
22	150	250	0,2+j0,11	0,095
23	0	0	0,614+j0,393	4,643
24	350	837,67	0,614+j0,393	0,183
25	0	0	0,614+j0,393	1,216
26	156	521,06	0,614+j0,393	0,119
27	1	200	0,614+j0,393	1,359
28	371	945,91	0,614+j0,393	4,682
29	0	0	0,614+j0,393	0,986
30	0	0	1,074+j0,4	2,776
31	1	13,2	1,074+j0,4	0,342
32	0	0	1,074+j0,4	0,368
33	1	50	1,074+j0,4	0,453
34	1	25	1,074+j0,4	1,517
35	0	0	0,614+j0,393	2,715
36	1	6,6	0,614+j0,393	0,653
37	0	0	0,614+j0,393	3,08
38	4	24,2	0,25+j0,1	0,071
39	387	955,65	0,614+j0,393	0,503
40	0	0	0,614+j0,393	1,422
41	0	0	0,614+j0,393	0,196
42	10	40,7	0,614+j0,393	0,456
43	0	0	0,614+j0,393	0,19
44	24	105,29	0,614+j0,393	0,22
45	60	100	0,614+j0,393	0,05
46	0	0	0,614+j0,393	0,081
47	1	25	0,614+j0,393	0,334
48	0	0	0,614+j0,393	0,99
49	1	0	1,074+j0,4	0,025
50	0	0	0,614+j0,393	0,719
51	1	25	0,614+j0,393	0,109
52	0	0	0,614+j0,393	2,968
53	1	25	0,614+j0,393	0,198
54	279	723,37	0,614+j0,393	1,797
55	0	0	0,614+j0,393	0,257
56	10	27,5	0,614+j0,393	0,058
57	0	0	0,614+j0,393	2,183
58	167	478,85	0,614+j0,393	0,125
59	0	0	0,614+j0,393	0,961
60	111	209,09	0,614+j0,393	1,862
61	1	25	0,614+j0,393	0,834

In Table 4 load refers to the load installed in this node, that is, the maximum power that consumers can demand. Line data refers to the line that ends in the corresponding ending node.

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