PLANNING OF DISTRIBUTED GENERATION DISPATCH IN DISTRIBUTION NETWORKS

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ABSTRACT

The volume of Distributed Generation (DG) capacity connected to distribution networks is growing quickly worldwide. Due to the inherent variable nature of renewable sources, such as wind or hydro, or low-carbon technologies, such as CHP, contracts are based on energy produced rather than power availability. Consequently, DG plants are typically not dispatched. However, an adequate dispatch strategy of these generators could provide a number of benefits to distribution network operators (DNOs).

This paper presents, from the economic perspective of a DNO, a comparison between the integration of DG plants with and without dispatch capabilities.

A Genetic Algorithm (GA) is applied to define the dispatch strategy (i.e., generation pattern) in a way that the costs related to energy losses and network investment (related to reinforcements and OPEX) are minimised. Here, small hydro generators (less than 30-MW of capacity, run of river), which are very common in Brazil, are considered given its (relatively) more predictable nature. Multiple small hydro DG plants are investigated considering a horizon of a year represented in twelve demand scenarios. The proposed methodology was applied to the IEEE 34-bus test feeder. Results are presented and discussed.

NOMENCLATURE

The notation in this paper is state bellow for quick reference.

A. Data

T	Electricity Tariff. (USD$/MWh) [1]
$\max(F_l^{DG-on})$	Maximum power flow through line l, considering the DG plants are connected. (MW).
$\max\left(F_l^{DG-off}\right)$	Maximum power flow through line/transformer l, considering no DG plants. (MW).
n	Number of elements (lines or transformer) in the network.
T_l^I	Cost of reinforcing line/transformer l. It represents the relation between the annual cost of the l element and the maximum power throwing for this element in a year. (USD$/MW).
T_m^U	Distribution use of system charge for month m. (USD$/MW)
n_{DG}	Number of DG plants in the network.
G_i^{cap}	Capacity of the DG plant located at bus i. (MW).
$Gmax_i^m$	Maximum power production of DG plant located at bus i in month m. (MW).
V_{min}	Lower and upper voltage limits allowed for each bus of the network. (V).
V_{max}	Upper voltage limit allowed in each bus of the system. (V)
S_l^m	Power flow through line/transformer l in month m. (MVA).
S_l^{max}	Maximum power flow permitted through line/transformer l. (MVA).
G_i^m	Power production of DG plant located at bus i in month m. (MW).

B. Sets

Ω_b	Buses.
Ω_L	Lines/transformers.
Ω_G	DG plants.
Ω_m	Months in the studied horizon (a year).

C. Results

L_m^{DG-on}	Energy losses in month m, considering the DG plants are connected. (MWh).
L_m^{DG-off}	Energy losses in month m, without DG plants. (MWh).
C_a^T	Annual distribution cost. (USD$).
C_a^L	Annual cost of energy losses. (USD$).
C_a^I	Annual investment required. (USD$).
R_a^U	Annual revenue due to distribution use of system charges. (USD$).

INTRODUCTION

In recent years the volume of distributed generation (DG) capacity connected to distribution networks has grown at a fast pace worldwide, a trend that is expected to continue in the near future. DG is generally defined as generation connected to the distribution network, irrespective of its size or type. However, given the incentives that governments have placed to promote low-carbon technologies, it is common for distribution network operators (DNOs) to have more and more utility-scale renewable (or low-carbon)-based DG developments.

Given that distribution networks were traditionally designed only to supply demand, i.e., to cater for

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[1] 1 R$ ~ 1.7 US$ on January 2011.

unidirectional power flows, the integration of DG bring about a number of technical and economical challenges extensively reported in the literature [1].

Due to the inherent variable nature of renewable sources, such as wind or hydro, or low-carbon technologies, such as CHP, contracts are based on energy produced rather than power availability. Consequently, DG plants are typically not dispatched, limiting DNOs in their ability to optimally manage the available devices and network participants in order to reduce costs. However, if DG dispatch was possible, an adequate strategy of these generators could provide a number of benefits to DNOs.

In this work, it is presented a Genetic Algorithm (GA) able to determine the most cost-effective DG dispatch strategy (or generation pattern) that, from the economic perspective of the DNO, minimises the costs related to energy losses and network investment (related to reinforcements and operational expenditure) brought about by the integration of DG. Here, small hydro generators (less than 30-MW of capacity, run of river), which are very common in Brazil, are considered given its (relatively) more predictable nature. Multiple small run-of-river hydro DG plants are investigated considering a horizon of a year represented in twelve demand scenarios. The proposed methodology is applied to the IEEE 34-bus test feeder.

This paper is organised as follows. Section 2 provides the necessary information to calculate the economic impact of DG plants on the DNO revenues (based on losses, required investment and use of system charges). Section 3 describes the optimisation technique used to minimise the economic impact by adopting dispatch strategies. Results and the corresponding analysis using the IEEE 34-bus test feeder are presented in section 4. Finally, conclusions are drawn in section 5.

ECONOMIC IMPACT OF DG PLANTS

To evaluate the DG impact on the DNO revenue, three different aspects were considered: the cost of energy losses in the network, the cost of network investment (including reinforcements and OPEX), and the distribution use of system charges (paid by the DG owners/operators to the DNO). Thus, the total distribution cost to be assumed by the DNO (using a horizon of a year) can be expressed by the following equation.

$$C_a^T = C_a^L + C_a^I - R_a^U \qquad (1)$$

Energy Losses

Energy losses in a distribution network can be obtained by performing power flow analyses for all the corresponding demand scenarios (including generation if present). In this work, the studied year is divided in twelve demand scenarios, i.e., each month is characterised by a single demand scenario. A price of 120 USD$/MWh [2] was used to calculate the cost of energy losses. The cost associated with energy losses and the integration of DG plants can be calculated by:

$$C_a^L = T\left(\sum_{m\in\Omega_m} L_m^{DG-on} - L_m^{DG-off}\right) \qquad (2)$$

Note that in (2) C_a^L can be either positive or negative. This means that if the energy losses with DG plants are smaller than those without DG, then impact of having generators is beneficial to the DNO.

Network Invesment

To define the cost associated with network investment (including reinforcements and OPEX), the Nodal method [6] is used. In this method, it is assumed that all equipment (lines, transformers, etc.) have an annual cost associated to them. This cost covers the transmission (in this case distribution) network maintenance, planning of new infrastructure (i.e., reinforcements), and operation cost; and it should be assumed by the users of the system.

To determine the responsibility of the cost the power flow in each line is associated with the cost of the line. Thus, there is a direct relationship between power flow and the above mentioned cost.

For the proposed methodology, this analysis can be applied considering, hypothetically, that the cost of reinforcement and operation of the distribution network should be recovered annually and that this cost would be directly related to the maximum power flow through the distribution lines/transformers in the studied year.

For the case without DG, the total cost is basically the network's OPEX. When DG is connected to the network, this cost (now including potential reinforcements or the corresponding deferral of them) can increase or decrease, depending on the power flows through the lines and transformers. Thus, the difference between the maximum power flow through each equipment, with and without DG, during the studied horizon (a year), represents either the necessary cost to reinforce the distribution system, or the profit associated with the deferral of network investments. Thus, the extra network investment in a system with DG can be obtained by:

$$C_a^I = \sum_{l\in\Omega_m}\left\{\left[max\left(F_l^{GD-on}\right) - max\left(F_l^{GD-off}\right)\right]T_l^I\right\} \qquad (3)$$

Note that in (3) the investment for any line/transformer l can be positive or negative. It means that when the maximum power flow through l caused by DG plants is greater than that without DG, then the connection of DG contributes to anticipate network reinforcements. On the other hand, the investment is negative when the maximum power flow through l, with DG, is less than

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[2] 70.59 USD$/MWh is a typical rate to distribution companies in Brazil

that without DG. In this case, DG helps deferring investment due to network reinforcements.

Distribution Use of System Charges

According to ANEEL, the Brazilian electricity market regulator, generators (and certain big consumers) pay the DNOs for the use of the system. This is a monthly fee based on the size (i.e., capacity) of the generators and big consumers [7]. Here it is considered that during the studied period the DG nominal capacity is known and does not change, making the resulting value fixed every month. The current distribution use of system charge is 1.54 USD$/kW [8]. Thus, the corresponding annual revenue for the DNO from all existing DG plants is:

$$R_a^U = 12\left[\sum_{i\in\Omega_G} 2.62\cdot\left(G_i^{cap}\right)\right] \qquad (4)$$

Note that (4) contributes to decrease the annual distribution cost (see (1)).

FORMULATION OF THE PROBLEM

In this work a Genetic Algorithm was used to optimise the dispatch strategy (only active power) of DG plants. The technique is aimed at minimising the annual distribution cost presented previously. Thus, the optimisation model can be expressed as follows:

$$\underset{G_i^m\geq 0}{Min}\ C_a^T \qquad (5)$$

Subject to:

$$V_{min} \leq V_i^m \leq V_{max}\ , \forall\ i \in \Omega_b; \forall\ m \in \Omega_m. \qquad (5.1)$$

$$S_l^m \leq\ S_l^{max}, \forall\ l \in \Omega_L \qquad (5.2)$$

$$G_i^m \leq Gmax_i^m\ , \forall\ i \in \Omega_G;\ \forall\ m \in \Omega_m. \qquad (5.3)$$

The first constraint that (5) is subject to determines that the voltage level at each bus remains between statutory limits during the whole studied horizon. The second constraint determines that the power flow through line or transformer *l* should be limited by the corresponding thermal capacity. The last constraint imposes that power generation should respect the maximum generation available in month *m*. Given that the DG plants adopted in this work are small hydro power plants, their power production is limited by the river inflow, which changes each month. In this work, these maximum power outputs were obtained from real data obtained from a small hydro that is going to connect to the Brazilian DNO Light (Rio de Janeiro). We reproduced its annual generation pattern to define the maximum power outputs of the generators studied in this work.

TESTS AND RESULTS

In this section, tests and results are presented and discussed by using the IEEE 34-bus system [7] shown in Figure 1. The test feeder was adapted to cater for the proposed study: capacitors were removed, loads were increased and the line impedances were modified. Three DG plants are considered and locasted at buses 4, 18 and 23.

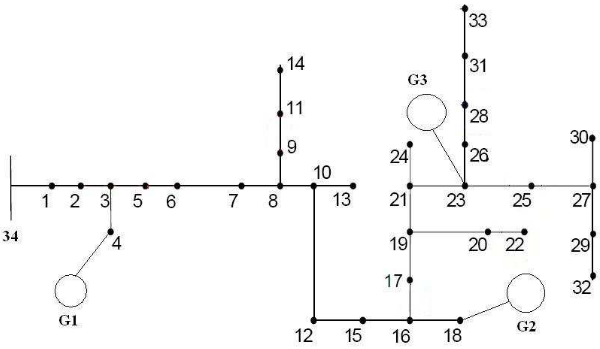

Figure 1: IEEE 34-bus system with DGs.

The first test was made considering just one generator of 15 MW connected at bus 23, and then, the second test was made by using simultaneous connection of three generators of 5 MW at the buses 4, 18 and 23, as shown in the Fig. 1. The idea behind these tests is to show the difference between the impact of one generator installed close to load centre and that of considering three generators the spread by the network. The capacity factor of the adopted hydro resource is 89.7%.

For the configuration with one generator, the annual average dispatch possible, due to the seasonality considered, was 9.27 MW (a capacity factor of 61.8%). For the configuration with three generators, the annual average dispatch of the generator 1 was 2.55 MW, generator 2 was 3.89 MW and of the generator 3 was 3.83 MW, also due to the seasonality considered.

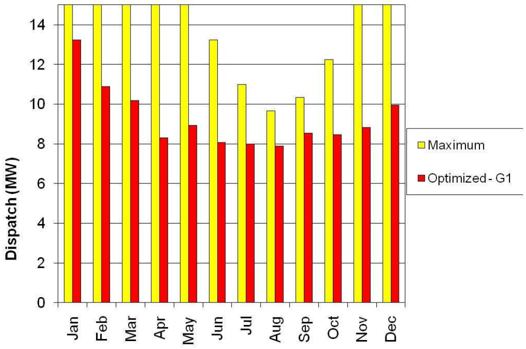

Figure 2: Optimized dispatch VS maximum generation for the first configuration.

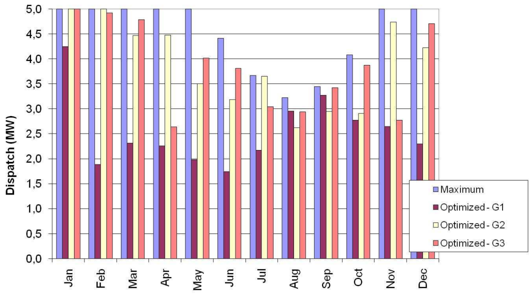

Figure 3: Optimized dispatch VS maximum generation for the second configuration.

Figure 2 and Figure 3 present the monthly optimised dispatch and the maximum power generation (worst case scenario) for each of the generators in both case studies.
The results, in both cases, show that the optimisation process finds significantly different dispatch strategies (generation patterns) from that following the maximum available resource (i.e., no dispatch).
Table 1 presents the disaggregated annual distribution cost for the optimised dispatch and the maximum available generation considering both case studies. The results clearly indicate a significant advantage in using the optimal dispatch as opposed to adopting no control at all (maximum available output). In the first case, the profit for the DNO is approximately USD$4.3m. This represents a 72% increase from the profit obtained when generation is not dispatched. As for the case study with three DG plants, the optimised dispatch resulted in a profit of USD$3.3m, 10% more if no dispatch was adopted.

Table 1: Disaggregated Annual Distribution Cost (USD$x1000).

Config.	Dispatch	C_a^L	C_a^I	R_a^U	C_a^T
1	(Max)	229.8	-2454.3	277.4	-2501.8
	(Optm.)	-78.1	-3955.8	277.4	-4311.4
2	(Max)	-67.8	-2619.9	277.4	-2965.2
	(Optm.)	-68.6	-2924.8	277.4	-3270.8

It is important to also understand that by dispatching generation the generator owner/operator loses profit as it is effectively limiting its ability of making the most of the available resource. The load factor considered for the small hydros analyzed in this work was 90%. This commercial drawback can be overcome to some extent if the DNO provides incentives or compensation that counteracts the profit lost by the generators.
Table 2 presents the annual distribution cost and the corresponding profit lost by the dispatched DG plants. For both case studies, the gains obtained by the DNO surpass the lost of profit suffered by the generators. While this might suggest that there is scope for compensation, it also has to be highlighted that the final 'net' value for the DNO would not be as beneficial as a scenario without dispatch.

Table 2: Annual Distribution Cost and Profit Lost by the DG plants (USD$x1000).

Configuration	C_a^L	Losses of the generators
1	-4311.4	2588
2	-3270.8	1973.8

CONCLUSION

This paper presents, from the DNO perspective, a new approach to cost-effectively manage distribution networks with DG plants by applying generation dispatch. This approach takes into account the cost of energy losses, network investment (including reinforcements and OPEX), and distribution use of system charges. The results indicate that it is possible to increase DNO's profitability by optimally defining a generation dispatch strategy. However, commercial arrangements need to be in place to compensate DG owners/operators for the corresponding loss of profit.

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