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# ON SIZING AND PLACEMENT OF THE RENEWABLE ENERGY SOURCES IN ELECTRICAL DISTRIBUTION NETWORKS

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***Abstract:*** *This paper deals with the establishment of the optimal size and placement of a distributed generation (DG) unit in the different buses of a low voltage radial distribution network applying the U-shape curve fitting method with the criterion of system power loss minimization. For modeling and simulation of a test network, the NEPLAN software is used, obtaining information about power flow analysis, voltage level in buses and power loss in branches of network. The results show that the U-shape curve fitting method could be applied for large number of buses in radial networks.*

***Key words:*** *distribution generation, LV test distribution network, size and placement optimization, U-shape curve fitting method.*

## 1. Introduction

Nowadays, the evolution of distribution generation (DG) is accelerated due to the new DG technologies, the constrains on the expansion of distribution networks, the increased customer demands for highly reliable electricity, the electric market liberalization, and climate change issues [1] , [2], [5], [11].

The renewable sources (hydro, wind, solar, geothermal biomass and wave energy), naturally scatered around the Earth and with smoller capacity, are appropriate for integration in the electric distribution systems. But, the impact of introduction of the renewable DG units in power system could be positive or negative, depending on the operating conditions of the distribution system, and on the DG unit characteristics [6], [7], [15]. Positive technical, economic and environmental benefit includs: reduction of the power losses, improvement of the voltage profile, reduction of the pollutant emission, amelioration of the utility system reliability and power quality.

On the other hand, the large-scale introduction of decentralized DG units may lead to instability of the voltage profile, due to the bi-directional power flows and the complicated reactive power flows arising when insufficient control is introduced. Additionally, bi-directional power flows make difficult to tune the protection systems in the grid, because short-circuits and overloads are supplied by multiple sources, each

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independently not detecting the anomaly.

A study realized in [15] shows that the losses in distribution networks occupy more than 80% of overall losses in power system, being produced through losses in cables and lines (cca. 60%), losses in transformers (cca. 24%) and in auxiliary equipment (about 3%). Because the losses in medium voltage (MV) or low voltage (LV) cables and lines could be of order (20-80) kW/km, many studies are concentrated to the reduction of this category of losses, one of solution being to introduce the DG units with optimal size and placement in specific buses, so that the losses in distribution network to be minimized [4], [8], [14], [15].

In this paper a synthetic analysis on the analytical methods developed for establishing the optimal size and placement of DG units in distribution networks is done, and, as application, the optimal size and placement of a DG unit in a LV distribution network is obtained using the *U*-shape curve fitting method for minimisation of the power loss in the network.

## 2. Methods for Establishing Optimum Size and Location of DG Units

The problem to establish the best placement and sizes of DG units in distribution networks is a complex combinatorial optimization issue, and various methods have been developed: classical methods (second order algorithms), the meta-heuristics approaches (with genetic algorithms, fuzzy methods etc.) and analytical methods [8], [9], [12], [13]. In some methods the reconfiguration of the distribution networks is take in account [3], [4], [10], [12].

In the analytical studies, optimal placement of the DG units is determined for the various distribution load profiles, or considering the effect of static models [15]. Usually, the optimal size and location of DG units is calculated based on successive load flows and loss sensitivity analyse, using the criterion of power loss minimization in the network.

Many efforts have been made to overcome these difficulties, and actual techniques propose to apply either the proper modification of existing methods, as Newton-Raphson and Gauss Seidel methods, either the backward and forward sweep processes using Kirchhoff's laws [4], [7], [9], [14].

In backward and forward sweep methods, the power losses determination is done, usually assuming that the three-phase radial distribution network is balanced and can be represented by their equivalent single-line diagram.

By applying the backward and forward methods the power flow is obtained. Also, the active power loss in the branch $P_{loss}(i,j)$ between buses $i$ and $j$ can be calculated. The total power loss of all branches is:

$$P_{tot,loss} = \sum_{n=1}^{n-1} P_{loss}(i,j), \tag{1}$$

where $n$ is the number of buses. For power loss minimization the classical or artificial intelligence search algorithms based on successive load flows calculation are used.

In [8] and [12] the loss sensitivity analyse is developed for obtaining the optimum size and location of DG units. The loss sensitivity factor (LSF) is defined as the derivation of the *k*-th branch power loss per *k*-th bus injected real power $P_i$, as:

$$LSF = \frac{\partial P_{lossj}}{\partial P_i} \tag{2}$$

A procedure is proposed in [12]: obtaining the LSFs with the recurrence system of equations, then, they are arranged in descendent order for all buses. The LSF value will decide the sequence in which buses are to be considered for DG unit installation. Then, other constraints are verify, for example, to restrain the voltages along the radial system within 1±0.05 pu.

The *U*-shape energy loss curve method is *b*ased on the fact that when the power $S_{DG}$ injected by the DG unit increases, the power loss $P_{loss}$ in distribution network reduces. However, when the power injected $S_{DG}$ exceeds the optimal rate, due to the large power injection, the power loss $P_{loss}$ increases, the *U*-shape power loss curve method was developed to assess the optimal size of DG with specific power factor [9].

The power loss curve function can be expressed by relation:

$$P_{loss} = a \cdot S_{DG}^2 + b \cdot S_{DG} + c \tag{3}$$

The minimum of the relation (3) is obtained through derivation, and the optimum DG size $S_{DG}^{opt}$ and the minimum value of power loss $P_{loss}^{\min}$ is obtained with:

$$S_{DG}^{opt} = -\frac{b}{2a}; \qquad P_{loss}^{\min} = \frac{b^2 - 4ac}{4a} \tag{4}$$

In [4] it is mentioned that for calculation of the variables *a*, *b* and *c*, it is required to perform the load flow program at least three times for different DG power and record the power loss for each of the DG sizes. Then, by replacing the values in relation (3), there would be three equations with three unknown variables that can be directly calculated. After assessing the variables *a*, *b* and *c*, it is straightforward to calculate the optimal size of the DG. One problem is that the *U*-shape curve fitting method was applied for the estimation of the size for a single DG unit.

In this study, an application is proposed to establish the optimal size and placement of the distribution generation units in a low voltage test distribution network, applying the *U*-shaped curve fitting method for minimization of the power loss in the system, using the NEPLAN software.

## 3. Application for 6-Buses Test Distribution Network

The task is to find the optimum size and placement of the DG unit in a test distribution network with 6 branches, with the criterion of minimum losses in network branches and without the violation of the bus voltage level.

### 3.1. Test Network and Procedure Description

In Figure 1 the electric scheme of the 6 buses radial network in which bus 1 is as reference is shown. In Table 1 the parameters of LV test distribution network are described.

The following hypotheses are considered:

- The three-phase test distribution network is of radial type, with a rated voltage of 0.4 kV, supplied from a substation with a transformer of 630 kVA, 20/0.4 kV, having 6 buses (from 2 to 7) and bus 1 as reference (Figure 1);
- The load in the network buses is balanced and constant, of inductive character, with power factor value between 0.60-0.92;
- Total load power is $P_{load}$ = 257 kW and $Q_{load}$ = 166 kVAr, respectively, $S_{load\text{-}tot}$ = 309.34 kVA;
- Parameters of electric branches are known and are designed to cover the maximum load of the network (Table 1);
- A DG unit of the specific power ($P_{DG}$, $Q_{DG}$, $S_{DG}$) is available, and can be introduced in different buses of the network.

The following steps have been done to establish the optimum placement and size of the DG unit:

- Establishing a set of DG power values $\{S_{DG1} = 0, S_{DG2},..., S_{DGn} = S_{load\text{-}tot}\}$ with valuable power of DG unit to be introduce in the buses of test network;

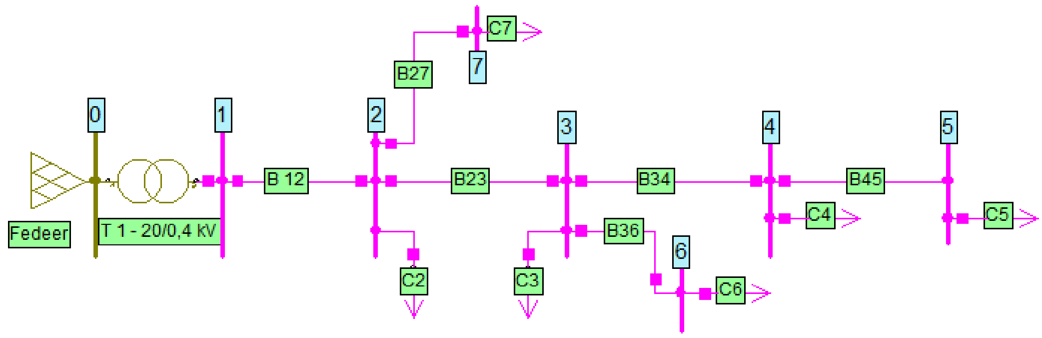



Fig. 1. *Electrical scheme of LV test distribution network, with bus 1 as reference*

*Parameters of LV test distribution network* Table 1

| Bus | Branch | Length [m] | Cable type | $P_{load}$ [kW] | $Q_{load}$ [kVAr] | cosφ |
|---|---|---|---|---|---|---|
| N2 | $B_{12}$ | 100 | KS 3x240/240 | 55 | 25 | 0.910 |
| N3 | $B_{23}$ | 100 | KS 3x240/240 | 32 | 25 | 0.788 |
| N4 | $B_{34}$ | 100 | KS 3x240/240 | 40 | 20 | 0.894 |
| N5 | $B_{45}$ | 100 | KS 3x240/240 | 35 | 40 | 0.659 |
| N6 | $B_{36}$ | 200 | NYCWY 3x 95/50 | 65 | 35 | 0.880 |
| N7 | $B_{27}$ | 200 | NYCWY 3x 95/50 50 | 30 | 21 | 0.819 |

- Running the program in NEPLAN software, considering the DG unit introduced successively, in all buses of the radial network (except the reference bus), and registering the values of the active power loss strings $\{P_{loss1} ... P_{lossn}\}_{n=2...7}$;

- Establishing the *U*-shape fitted curve (3) and the coordinates of the minimum point ( $S_{DG}^{opt}$ , $P_{loss}^{\min}$ ) with the relations (4);
- Comparing the values of losses obtained with *U*-shape procedure and the values of losses obtained with NEPLAN software;
- Verification of voltage profile in network for $S_{DG}^{opt}$ values;
- Establish a hierarchy of the buses in which the DG unit can be placed, satisfying and other requirements.

### 3.2. Results on Optimal Sizing of DG Unit

By running the NEPLAN software, the power flow is obtained for a string of the of DG unit apparent power values, in kVA, {$S_{DGi}$} = {0, 40, 70, 100, 130, 160, 190, 220, 250, 280, 310}, and the corresponding power loss $P_{loss}$ is extracted. In Table 2 the data obtained running the NEPLAN software are presented.

The *U*-shape fitted curves obtained for test network without and with introduction of one DG unit in each bus of the network are shown in Figure 2.

Table 2

*String values of power loss {$P_{loss}$) obtained with NEPLAN software, when different values of DG unit power {$S_{DGi}$} are considered*

| String values of DG unit power | | | | String values of power loss $P_{loss}$ when DG unit is introduced in the following buses [kW] | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $S_{DG}$ [kVA] | $P_{DG}$ [kW] | $Q_{DG}$ [kVAr] | cos$\varphi_{DGi}$ | N2 | N3 | N4 | N5 | N6 | N7 |
| - | - | - | - | 9.82 | 9.82 | 9.82 | 9.82 | 9.82 | 9.82 |
| 10 | 9 | 4 | 0.94 | 9.50 | 9.28 | 9.18 | 9.13 | 8.87 | 9.33 |
| 40 | 37 | 16 | 0.91 | 8.57 | 7.74 | 7.41 | 7.29 | 6.47 | 8.22 |
| 70 | 64 | 27 | 0.92 | 7.78 | 6.48 | 6.04 | 5.94 | 4.93 | 7.73 |
| 100 | 92 | 39 | 0.92 | 7.06 | 5.37 | 4.91 | 4.93 | 4.02 | 7.76 |
| 130 | 120 | 51 | 0.92 | 6.44 | 4.46 | 4.08 | 4.31 | 3.80 | 8.33 |
| 160 | 147 | 63 | 0.91 | 5.92 | 3.77 | 3.55 | 4.06 | 4.17 | 9.34 |
| 190 | 175 | 74 | 0.92 | 5.5 | 3.27 | 3.30 | 4.16 | 5.12 | 10.83 |
| 220 | 202 | 86 | 0.92 | 5.17 | 2.95 | 3.29 | 4.56 | 6.56 | 12.69 |
| 250 | 230 | 98 | 0.92 | 4.93 | 2.80 | 3.54 | 5.3 | 8.53 | 15.03 |
| 280 | 258 | 110 | 0.92 | 4.78 | 2.83 | 4.04 | 6.33 | 10.98 | 17.75 |
| 310 | 285 | 121 | 0.92 | 4.72 | 3.02 | 4.75 | 7.61 | 13.74 | 20.70 |
| 340 | 313 | 133 | 0.92 | 4.74 | 3.38 | 5.70 | 9.2 | 17.01 | 24.11 |

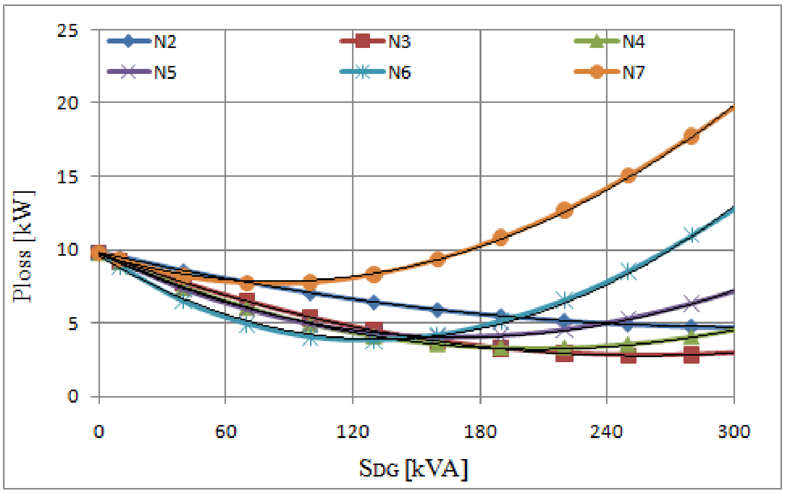



Fig. 2. *U-fitted curves: dependence of power loss in test network on aparent power of DG unit*

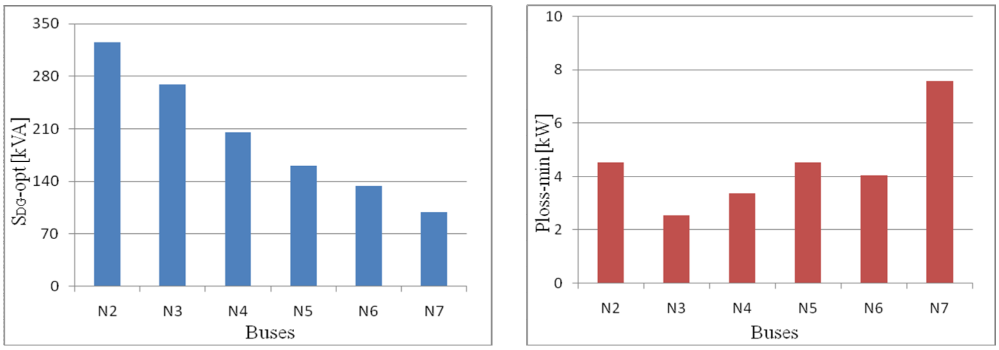
The obtained *U*-fitted curves parameters *a, b., c,* are shown in Table 3, in which the correlation factors described by $R^2$ are given, together with the relative deviation between the values of losses $\Delta P_{loss}$ [%] obtained with *U*-shape procedure and values of losses obtained with NEPLAN software in the case when in buses of the network, step by step, the $S_{DG}$ of optimum value is introduced.

A synthesis of obtained data for optimal size and placement of DG unit is shown in Figure 3a and 3b. The voltage profiles obtained with NEPLAN software, in the buses of test network with and without introduction of a DG unit, corresponding to the optimal size obtained with *U*-shape method, are shown in Figure 4a and 4b.

Table 3

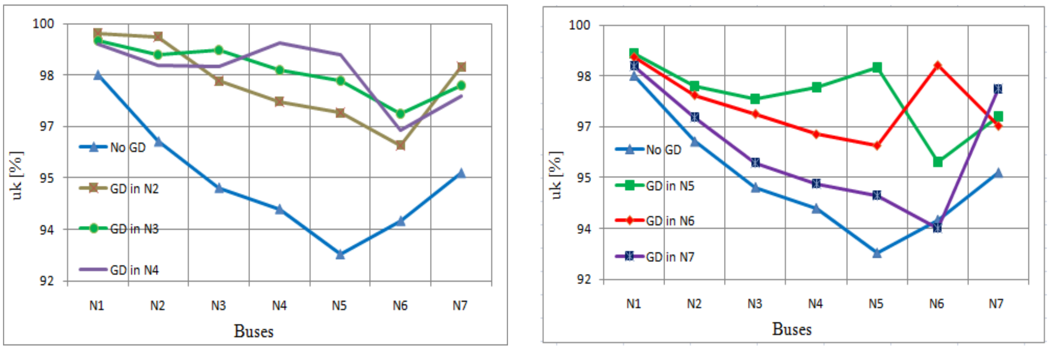
*U-fitted curves parameters of $P_{loss}=f(P_{DG})$, correlation factor R2, and relative deviation $\Delta P_{loss}$ [%] between the values of losses obtained with U-shape procedure and values of losses obtained with NEPLAN software*

| **Bus** | ***a*** | ***b*** | ***c*** | $R^2$ | $S_{DG}^{opt}$ **[kVA]** | $P_{loss\text{-}min}$ **U-shape [kW]** | $P_{loss\text{-}min}$ **NEPLAN [kW]** | $\Delta P_{loss}$ **[%]** |
|---|---|---|---|---|---|---|---|---|
| N2 | 0.00005 | -0.0325 | 9.8048 | 0.9999 | 325 | 4.52 | 4.71 | 3.96 |
| N3 | 0.00010 | -0.0538 | 9.7676 | 0.9997 | 269 | 2.53 | 2.79 | 9.27 |
| N4 | 0.00015 | -0.0618 | 9.7148 | 0.9986 | 206 | 3.35 | 3.26 | 2.74 |
| N5 | 0.00020 | -0.0641 | 9.6511 | 0.9969 | 160.25 | 4.52 | 4.06 | 11.21 |
| N6 | 0.00030 | -0.0803 | 9.4075 | 0.9965 | 133.83 | 4.03 | 3.81 | 5.88 |
| N7 | 0.00020 | -0.0395 | 9.5429 | 0.9990 | 98.75 | 7.59 | 7.75 | 2.03 |




a) b)

Fig. 3. *Optimal size of the DG unit aparent power and their location (a), and minimum losses in buses of test network when a DG unit with optimal power is installed (b)*




a) b)

Fig. 4. V*oltage profiles in the buses of test network without and with DG unit having optimal power placed in buses 2, 3, 4 (a), and placed in buses 5, 6, 7 (b)*

## 4. Conclusions

In this study, the method of *U*-shaped curve fitting method is applied to obtain the optimum size and location of a DG unit in a 6 buses low voltage test distribution network, using the NEPLAN software.

The results show that the method of *U*-shape curve fitting is efficient and precise but require a series of power flow calculations to obtain a good fitting of the correlation between power losses $P_{loss}$ in branches and DG unit power $S_{DG}$. Figure 3 shows that the minimum value of the power loss $P_{loss}^{min}$ = 2.53 kW was obtained, when in the bus N3 is included a PG unit of the apparent power $S_{DG}^{opt}$ =269 kVA. Figure 4 shows the improving of the quality of voltage profile in the network is done when the DG unit with optimal power is installed in buses N3, N4 or N5. The voltage profile is in admited limits.

NEPLAN software is appropriated to be used for implementation of the *U*-shaped curve fitting method for establishing the optimum size and location of a DG unit in the radial distribution networks.

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