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Distributed Generation Influence on the Voltage Level and Power Losses

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Abstract: The fast development of reduced size local systems destined to electric energy production poses the problem of their integration in the existing networks so much point of view of present norms Power Quality (PQ) as the usufruct discounted of advantages that ensue some. To the inverse, disorganized and non controlled introduction of these systems would lead to stroke on verse deterioration more and more increased from PQ. In this research, it is intended to introduce a simplified method as according to existing topology and space-temporal distribution of loads, it would allow the energy system operator to know active and reactive powers potential margins to inject at the network in order to reduce losses and to improve the level voltage. The gait adopted in this research is based on insertion of production Distributed Generation (DG) in various positions with application and verification on the East Algerian zone electrical network.

Key words: Distributed generation, power losses, voltage stability, optimization, power quality, Algeria

INTRODUCTION

The insertion within the existing electric networks of moderate size power generators using renewable energies spilled considerably with, on the one hand the internationalization necessity to limit seriously environment pollution and on the other hand contribution of new technologies using traditional fossil fuels (fuels batteries, micro turbines), used in cogeneration permitting to achieve a meaningful reduction of dismissals polluting. The strategic sector is without discussion the combined production thermal/electric energy, because it grants a considerable economy of primary energy and hence, a drastic reduction so many the raw materials put in use that of dismissals polluting generated under exploitation. However, the transport difficulty of thermal energy imposes us to assure facilities of cogeneration localization at place of heat use in order to pull the maximum of it from advantages, generating the necessary presence of multiple generators whole imposing network a perfect adequacy with the system in order to guarantee a sensitive improvement of the PQ in the absolute respect of the electric system security (Ballocchi *et al*., 2001).

Seen under another angle, the success of the distributed generation and with her the development of a technology in relation to another, will essentially depend on the electric energy market and existing practices, but in absence of specific regulation of the DG (Agustoni *et al*., 2002a; Castelli *et al*., 2001), the small producers will limit themselves to auto production without worrying of the service quality because they don't have again competitive force in a monopolistic environment.

The foreseeable growth of the DG in the energizing landscape let to foresee the setting in use of new rules permitting to exploit to best the offered technological opportunities and impose us to take account from now on because the growth of the power and the overlapping of these new means in relation with the availability of the primary energies, the infrastructures, the urbanization and the norms disrupt the correct network working and alter the PQ.

The goal of this research is therefore, to propose a simplified approach, which taking into account the topology and the nature of the existing loads would allow the system operator to know the potential active and reactive powers reserves to inject, in order to improve the voltage level and reduce the losses, knowing that the reduction of voltage variations is one of the most important aspects of the PQ considering the increasing sensitivity of the loads to the present disruptions in the network (Gemez and Morcos, 2002). Of another quoted the reduction of the losses, besides its energizing importance as for the improvement of the system output (Choi and Kim, 2001), converge towards the economic aspect constantly aimed by the distributor in its quest of competitiveness. Finally, the recommended approach will be applied and true on a targeted zone of the East Algerian electric network.

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Distributed generation impact on the distribution network exploitation: The Medium Voltage networks (MV) have in general a radial configuration as the circulation of the powers takes place in the sense: transportation network-station HV/MV-loads users. This simple architecture configuration for exploitation and protection puts seriousness problems of voltage regulating and currents distribution and mortgage all future network extension. For it, the insertion of small generators in the distribution network, traditionally passive, impose a general revision from then on so much their conception as their exploitation.

The major consequence ensuing of the distributed generation insertion, regardless of the generator type put in use, is the change of active and reactive powers transits (Kim and Kim, 2001) dragging important repercussions on the stabilization of the adequate voltage level, on the total powers losses level and also on the installed protections selectivity.

In this research, it will be concentrate on the working of the network in the normal exploitation conditions while, deepening the present research on the voltage and losses aspects banishing the protection to the ulterior researches.

Leaving because, voltage stabilization to the level near its nominal value guarantees a correct working of receptors and limitation of active power losses contributing to a better energizing efficiency of the network (Liang and Cheng, 2001) as very technical that economical, without losing view that the energizing and environmental aspect is one of the essential reasons of the distributed generation development, then it can be affirm that its exploitation optimization will very certainly contribute to make impose it in the immediate future.

For a transmission line of L_{ij} length joining the node i to the node j having for ligneous parameters resistance r_0 and reactance x_0 it will be able to determine with a good approximation the voltage losses ΔU_{ij} and active power losses ΔP_{ij} according to the active and reactive powers flows (P_{ij}, Q_{ij}) by the Eq. 1 and 2:

$$\Delta U_{ij} = \frac{r_0 \times L_{ij}}{U^2} P_{ij} + \frac{x_0 \times L_{ij}}{U^2} Q_{ij} \quad (1)$$

$$\Delta P_{ij} = \frac{r_0 \times L_{ij}}{U^2} P^2_{ij} + \frac{r_0 \times L_{ij}}{U^2} Q^2_{ij} \quad (2)$$

In the distribution networks, the admissible maximal voltage variation being of 5% it will keep like acceptable the hypothesis that voltage in every node is nominal and constant.

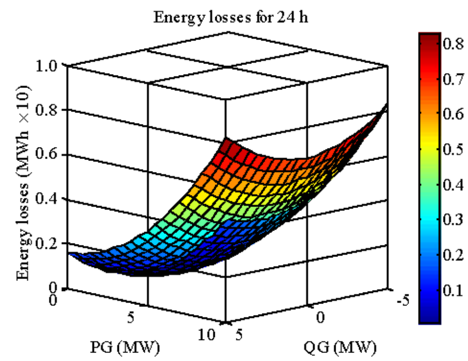

Fig. 1: Maximal variation of energy losses according to the distributed generation active and reactive powers

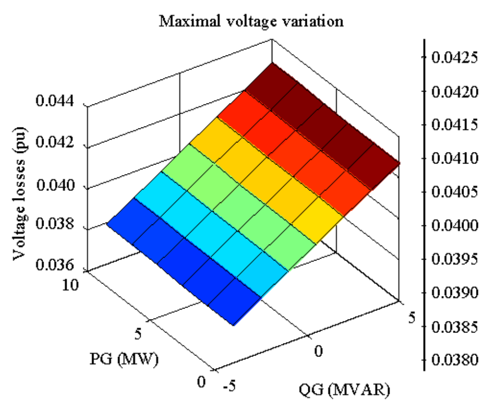

Fig. 2: Maximal variation of the voltage losses according to the distributed generation active and reactive powers

The preliminary analysis of the Eq. 1 and 2 based on normal exploitation conditions of the distribution network with loads power factor to the neighborhood of 0.90 leading a reactive power flow of half of the active (a lot less if we takes into account the transverse capacity of the aerial lines and more especially of the cables), a report r_0/x_0 of the order of 0.05 for the aerial lines and until, 1.4 for the cables, watch in a clear manner that the voltage losses are directly proportional of by the factors r_0 and x_0 to the powers flowed P_{ij}, Q_{ij} whereas, the active power losses have a quadratic relation with the powers flowed and only depend on the resistance. It can be affirm therefore that in normal working regime, the power losses undergo the preponderance of the active power influence whereas, the voltage losses remains proportional to the two united transits. Figure 1 and 2 put clearly, respectively in evidence the parabolic pace and the linear pace of the described relations.

In the gait to adopt for the choice of the distributed generation size it will be proceed as follows: first we optimize the active power value P_G that the generator should provide in order to minimize the energy lost by the network during a predefined cycle, because of facto for the values usual of the powers factors with which, the distributed generation functions, the influence of the reactive power on the losses is negligible such that shown by the Fig. 1.

The determination of the P_G value operated once, the power reactive value necessary Q_G is calculated in order to minimize the variations transmission line voltage.

From the Fig. 2, it is observed that for every value of active power P_G a value of the reactive power Q_G exists as the voltage maximal variation during the cycle reaches always the minima absolute.

MATERIALS AND METHODS

Active power P_G optimal value determination: The localized production systems, in particular those foreseen by the distributor himself, even and therefore, without specific orders of electric use limitations, generally operate at constant power active, because they are submitted to other constraints otherwise as the thermal energy production in the facilities of cogeneration for which, a weak load factor would lead a sensitive reduction of the electric output, whereas, it is not of the quite economic to practice load modulations. It will be keep the plausible hypothesis that the generator nourishes a reference load then and than therefore, once definite the necessary active power P_G to provide by the distributed production, this one will be maintained constant during the generator working time.

Supposing to want to connect in one node m of the MV transmission line (Fig. 3) composed of n sections, a generator of constant active power P_G. While, subdividing the exploitation cycle in p intervals of identical length time ΔT it will be write active and reactive power transits for the jth section as Eq. 3 and 4:

$$\forall j \le m:\ P_{tj} = \left(\sum_{i=j}^{n} Pch_{ti}\right) - P_G$$

$$Q_{tj} = \sum_{i=j}^{n} Qch_{ti}) - Q_G \qquad ((3)$$

$$\forall j > m \qquad PP_{tj} = \sum_{i=j}^{n} Pch_{ti}$$

$$QQ_{tj} = \sum_{i=j}^{n} Qch_{ti} \qquad (4)$$

with Pch_{ti} and Qch_{ti} the averages active and reactive powers of the load to the node i for the interval of time numbered t.

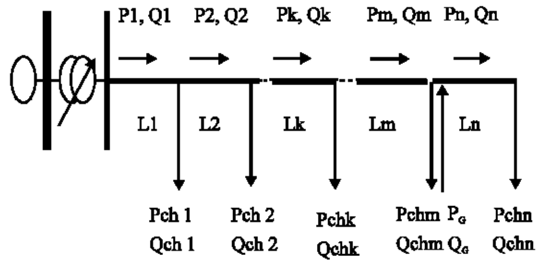

Fig. 3: Adjusting the production distributed to the MV network

It is to note that for exact calculations, it will be necessary to include at the reactive power flow, the reactive powers Q_Y generated by the transverse capacities of the transmission lines, because in the minimal regimes of load it is must expected important localized over voltages.

Supposing the used power by the load is constant during every time interval, the lost energy will be expressed in this interval by:

$$W_t = T\sum_{j=1}^{n} W_{tj} = \Delta T \times \sum_{j=1}^{m} \frac{r_0 \times L_j}{U^2}(P^2 t_j + Q^2 t_j) + \Delta T \times \sum_{j=m+1}^{n} \frac{r_0 \times L_j}{U^2}(PP^2{}_{tj} + QQ^2{}_{tj}) \qquad (5)$$

For the cycle, this one will

$$W = \sum_{t=1}^{p} Wt = \Delta T \times \sum_{t=1}^{p}\sum_{j=1}^{m} \frac{r_0 \times L_j}{U^2}(P^2 t_j + Q^2 t_j) + \Delta T \times \sum_{t=1}^{p}\sum_{j=m+1}^{n} \frac{r_0 \times L_j}{U^2}(PP^2{}_{tj} + QQ^2{}_{tj}) \qquad (6)$$

The final objective being to determine the necessary power P_G that the generator should provide to the ends to minimize the energy lost W, it would be necessary to look for the partial derivative annulment conditions $\partial W/\partial P_G$ taking account because the reactive power transit has a negligible influence on the active losses.

$$\text{Min}(W) \Rightarrow \frac{\partial W(P_G, Q_G)}{\partial P_G} = 0 \qquad (7)$$

The unique term in this equation depending on P_G is P_{tj}; it is why, the power optimal value depends only on the active power transit and this until, the generator adjusting node.

The equation resolution permits to estimate the necessary power to assign to the distributed generation to the node m in order to minimize the active losses.

$$P_G = \frac{\sum_{t=1}^{p}\sum_{j=1}^{m} L_j \times \sum_{i=1}^{n} P_{ti}}{p \times \sum_{j=1}^{m} L_j} \quad (8)$$

In the process describes, it is supposed that the power generated P_G is constant and satisfied the reference load, however, this one is able to evolve with the demand and the development of the distributed generation, it is imperative to foresee the setting up of local centers dispatching in the distribution network (Bhandari *et al*., 2004) in order to conduct a more compliant power distribution thus, generated.

Voltage optimization: The MV/LV distribution network is the place of predilection of shortcomings and disruptions converging toward the PQ deterioration, whereas, it nourishes more and more consumers to electronic technology basis who's working with extreme sensitivity to the applied voltage values. The insertion of a generator to the network, apart from it decreases the transmission lines load and changes the powers transit, if it proves to be correctly proportioned, contribute to improve meaningful way the voltage level. The types of regulating of the distributed generation have been analyzed by Agustoni *et al*. (2002 b) or it has been put in evidence that the regulating to constant voltage minimizes the voltage variations in the transmission line, but in practice this one is not used for economic reasons (complex regulators) and exploitation reasons (continuous variation of reactive power). It is prefered, the regulating with constant power factor, the ratio active/reactive power being maintained constant.

To the difference of the power losses for which, the pace being parabolic saw the passage by zero of the derivative corresponding to the minimum, the voltage variations are irregular and discontinuous because of the space-temporal load variation and can that made be positive for the over voltages or negative for the under voltage. The discontinues pace imposes us an retailed analysis of the network node by node therefore, and for every interval of time, it will be have several variables then to optimize what would complicate the gait and would prevent a serious practical application.

It proves to be appropriate to construct a P_G and Q_G continuous function that synthesize in an unique value the voltage variations state to the network nodes for a daily cycle.

To this end, it is chosen the objective function fu (P_G, Q_G) to minimize the voltage variations squares sum of the different nodes for different instants in the day. The square choice imposed itself to avoid the compensation effect on the one hand between positive gaps and negative gaps and on the other hand to have a continuous derivative making the minimization process simpler.

$$f_u(P_G, Q_G) = \sum_{t=1}^{p}\sum_{k=1}^{n} (\Delta U_{tk})^2 = \sum_{t=1}^{p}\sum_{k=1}^{n} (\alpha_{tk} - \beta_{km})^2 \quad (9)$$

where:

Δu_{tk} : Node k voltage variation for the interval t

α_{tk} : Loads contribution factor to the node k voltage variation

$$\alpha_{tk} = \frac{\sum_{j=1}^{k}\left[r_0 \times L_j \times (\sum_{i=j}^{n} P_{ti}) + x_0 \times L_j \times (\sum_{i=j}^{n} Q_{ti}) \right]}{U^2} \quad (10)$$

β_{tk} : Node m generator contribution factor to the node k voltage variation

$$\beta_{km} = \frac{\sum_{j=1}^{\min(m,k)} \left[(r_0 \times L_j \times P_G) + (x_0 \times L_j \times Q_G) \right]}{U^2} = \delta_{km} \times P_G + \lambda_{km} Q_G$$

with

$$\delta_{km} = \frac{\sum_{j=1}^{\min(m,k)} [r_0 \times L_j]}{U^2} \quad (11)$$

$$\lambda_{km} = \frac{\sum_{j=1}^{\min(m,k)} [x_0 \times L_j]}{U^2} \quad (12)$$

The objective being to minimize the function f_u we will have

$$\frac{\partial f_u(P_G, Q_G)}{\partial Q_G} = -\sum_{t=1}^{p}\sum_{k=1}^{n} 2 \times (\alpha_{tk} - \beta_{km}) \times \lambda_{km} = 0 \quad (13)$$

$$Q_G = \frac{\sum_{t=1}^{p}\sum_{k=1}^{n} (\alpha_{tk} \times \lambda_{km} - P_G \times \delta_{km} \times \lambda_{km})}{p \sum_{k=1}^{n} \lambda^2_{km}} \quad (14)$$

Equation 14 apart from it permits the determination of the necessary reactive power Q_G suggests us to use it in the setting of the reactive power compensation (some either the retained compensation device) because, it see that for $P_G = 0$ hopeless exists a Q_G value.

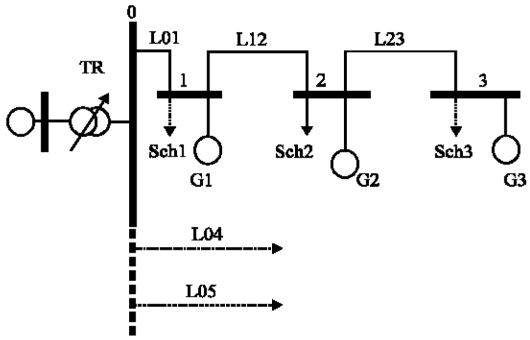

Fig. 4: Network test simplified diagram

The only inconvenience of this solution is that at the time of the minimal loads regimes has the risk of return reactive power toward the transportation network situated upstream.

As in practice the transmission line sections in cascade are homogeneous i.e., the same ligneous parameters r_0 and x_0, it is possible to demonstrate that the reactive power assigned to the generator and calculated by Eq. 14 is such that it minimizes the maximum voltage variation and with these conditions of working this variation doesn't depend on P_G or Q_G.

It can be put in evidence while, rewriting the Eq. 14 under the shape:

$$Q_G = \frac{\sum_{t=1}^{p}\sum_{k=1}^{n} \alpha_{tk}\lambda_{km}}{p.\sum_{k=1}^{n}\lambda^2_{km}} - \frac{r_0}{x_0}\times P_G = \Omega_m - \frac{r_0}{x_0}\times P_G \qquad (15)$$

The Ωm term depend solely of the space-temporal distribution loads and the position of connecting the generator to the network. From that we can rewrite the distributed generation contribution factor to the voltage variations like:

$$\beta_{km} = \frac{\sum_{j=1}^{\min(m,k)} x_0 \times L_j \times \Omega_m}{U^2} \qquad (16)$$

This last is independent of the generator power provided.

It is observed otherwise that the reactive power that must provide the generator decreases with the increase of the distributed generation size and it represents an advantage so much for the generator that will be less solicited that for the network that won't have excess of reactive power anymore and therefore, not of disturbs for the minimal loads regimes.

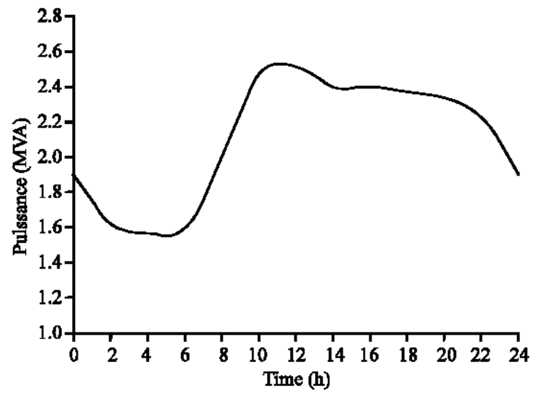

Fig. 5: Daily load stylized diagram

Validation of the method proposed by application to the network test: To validate the proposed method it is chose, the portion of the distribution network Annaba-Seybouse-Asmidal-El Hadjar composed (Fig. 4) like follows:

- A transformation station 60/30 kV, of nominal power 40 MVA to variable transformation report provided with regulator in charge
- An aerial line with three L01 sections, L12, L23 of lengths 3, 4 and 6 km
- Three nodes of loads to which, one will connect the generator of production distributed in turns
- A passive derivation of aerial lines in L04 cascade, L05

The loads stylized diagram for a cycle of 24 h for each load has been reported on the Fig. 5.

RESULTS AND DISCUSSION

For every position of connecting of the generator G1-G3 it is calculated the distributed generation optimal values P_G and Q_G according to the Eq. 8 and 14 and it is compared them with gotten results by the load flow method.

The gotten results are similar has those gotten by application of the classic iterative calculation; the small differences come, because for the method proposed voltage has been maintained constant to nodes (Table 1).

The voltages values in absence of distributed generation show us a voltage variation to the nodes greatly variable in the time, because of loads variations and in space, because of the transmission line impedance.

Table 1: Optimal values P_G and Q_G calculated by the proposed (prop) method and those affected by load flow (flow) for each generator position

DG position	P_G (MW) Prop	P_G (MW) Flow	Q_G (MVAR) Prop	Q_G (MVAR) Flow
G1	5.73	5.85	6.19	6.25
G2	4.77	4.90	2.88	2.65
G3	3.82	3.90	2.19	1.95

Table 2: Network working conditions with and without distributed generation

DG place	U_{max}-U_{min} (%) Prop	U_{max}-U_{min} (%) Flow	Energy losses W (MWh) (%) Prop	Energy losses W (MWh) (%) Flow	Efficiency η Prop	Efficiency η Flow
Without DG	4.4	-	2.8	-	97.96	-
With DG						
G1	2.9	2.9	1.4	1.46	98.98	98.94
G2	2.0	2.0	0.37	0.35	99.73	99.74
G3	2.2	2.0	0.46	0.44	99.66	99.68

Table 3: Voltage space-temporal distribution with and without distributed generation

DG	Voltage Max. (pu) Prop	Voltage Max. (pu) Flow	Voltage Min. (pu) Prop	Voltage Min. (pu) Flow
With DG	1.000	-	0.956	-
Without DG				
G1	1.014	1.014	0.985	0.985
G2	1.010	1.010	0.991	0.989
G3	1.013	1.010	0.991	0.989

After the determination of the P_G and Q_G powers following the connecting of the production distributed generation alternately to the different loads nodes kept and in the same way to the classic simulation by load flow, the results are regrouped in the Table 2 and 3.

It is noted that the distributed generation integration brings a clean improvement of the network working conditions as well in terms of voltage variations that of efficiency.

The best generator point connecting is the point 2 because it leads the minimum of voltage variations and power losses.

The point 1 too much brought closer of the transportation network permits a more important power injection, but requires a modest power factor to guarantee an acceptable working of the transmission line, as for the point 3 being to the extremity of the network offers a good benefit but it rather grants an reduced power injection.

It is observed whereas, the calculated optimal values by Eq. 14 is effectively those that privilege the minimization of the voltage variations in relation to the power losses and it to guarantee a better energy used quality.

CONCLUSION

The insertion of DG in the distribution network alters the power transits and by way of consequence disrupts its normal working.

In this research, it is proposed a method of approach to proportion in a suitable manner the distributed generation in order to minimize the voltage variations and the power losses at the same time.

We observed that the power losses are led mainly by the active power whereas, the voltage losses also depend a lot of active power that of the reactive power.

The recommended approach first aims the determination of the necessary active power to provide by the distributed generation in order to minimize the losses and then it is conducted the reactive power calculation and therefore of the power factor to impose at the PD in the goal to minimize the voltage losses.

Finally, the proposed method has been tested on a real network and has been validated compared to the classic iterative calculation by load flow.

In perspective this research will be able to be developed on networks to more complex configuration as the curly-netted network.

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