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A NEW APPROACH FOR THE VOLTAGE REGULATION IN MEDIUM VOLTAGE NETWORKS USING THE EXPERIMENTAL DESIGN METHOD

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Abstract. This work constitutes a new approach to the voltage control in medium voltage (MV) networks by using the Experimental Design method. This method, also referred to as Design of Experiments (DOE), is a powerful tool to establish and study the effects of multiple inputs (factors) on a desired output (response). The purpose is to obtain the best possible voltage profile along the feeders of the grid. Therefore, the studied response is the sum of the absolute values of the deviations between the voltage at each node of the network and the rated voltage. This response has thus to be minimized. The different considered factors to ensure this goal are the on-load tap changer (OLTC) of transformer and the reactive power compensation devices.

Keywords: Design of experiments, distribution systems, load-flow analysis, voltage control.

INTRODUCTION

Since several years, the voltage regulation in medium voltage networks has become more complex because of the increase of distributed generation (DG). Indeed, in the basic paradigm of power networks (i.e. without DG), the voltage profile was more predictable, as it was systematically characterized by a voltage drop along the feeders between the highly powered centralized generators and the different consumers. But now, distribution networks are subject to bidirectional power flows. New voltage control devices are thus required to maintain the voltage within its permitted range.

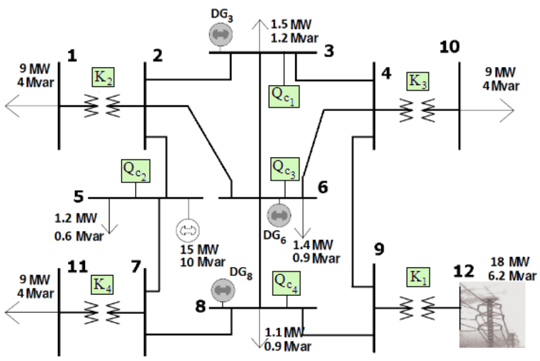
The most popular method currently used to this purpose is the on-load tap changer (OLTC) of transformer. The reactive power compensators are also useful to get a better voltage profile in a distribution network. The load-shedding (in case of overload) and the curtailment of the power generation (in case of oversupply) are also possible solutions but should only be used by the distribution network operator (DNO) as a last resort, as it often implies financial compensation for the service.

DESCRIPTION OF THE METHODOLOGY AND APPLICATION TO A 11 kV MESH GRID

Introduction of the proposed methodology and definition of the network

The Design of Experiments (DOE) method [1] is here employed for two purposes. A screening study is first carried out in order to select the most influential devices on the voltage for the considered network. The purpose is to find the optimal location of the most appropriate devices for the voltage control in the grid. Then, depending on the load and generation in the grid, the levels of those selected devices are optimized by using a response surface methodology (RSM) in order to obtain the best voltage profile along all the feeders. This process presents thus a great interest for DSOs for the operational management of the voltage in distribution networks.

The developed process is applied on the mesh grid presented in [2]. Indeed, the voltage in mesh grids is generally more complicated to model and to control comparing to radial networks, because of their structure with a lot of connections between the different nodes. The single phase diagram and the table of the electric characteristics of the different lines and transformers are shown in Figure 1.



Line/Transformer	Nodes	R (*pu*)	X (*pu*)	S_{max} (MVA)
transformer	1-2	0.1667	0	30
line	2-3	0.48	0.3	∞
line	2-5	0.24	0.15	∞
line	2-6	0.72	0.45	∞
line	3-4	0.64	0.4	∞
line	3-6	0.64	0.4	∞
line	4-6	0.48	0.3	∞
line	4-9	0.66	0.35	40
transformer	4-10	0	0.1667	30
line	5-7	0.688	0.43	∞
line	6-8	0.768	0.48	∞
line	7-8	0.56	0.35	∞
transformer	7-11	0	0.1667	30
line	8-9	0.768	0.48	∞
transformer	9-12	0	0.055	90

Figure 1. 12-bus mesh network and table of line/transformer characteristics [2].

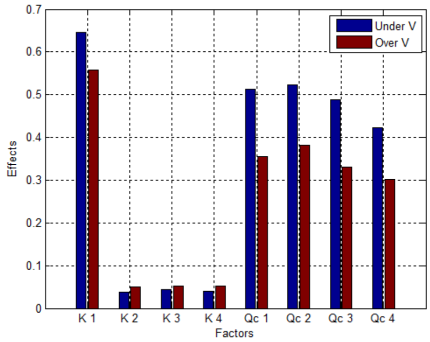
Furthermore, because of the different penetration rate of DG in the evolving distribution networks, both under- and over-voltages issues must be studied. Therefore, the methodology is applied to the same network for two extreme cases. On the one hand, only one generator is connected to the network (at node 5). Without the action of voltage control devices, under-voltages appear at the majority of the nodes. On the other hand, three more DG units are added to the same network, respectively at nodes 3 (DG3), 6 (DG6) and 8 (DG8), and the opposite phenomenon is in this case observed. The purpose of the work is therefore to find the most suitable configuration of devices to install on the grid for handling both scenarios ("Under V" and "Over V"). The optimization methodology is then applied to the obtained grid in order to improve the voltage profile.

Results

The screening study is performed for the two considered topologies, and the influence of 8 factors is investigated. Those factors are highlighted in Figure 1 and the definition of their ranges of variation is presented in Figure 2(a). Each transformer is equipped with an on-load tap changer on the secondary winding, which allows to adjust the turn ratios (K_i) of the transformers. Those constitute therefore the four first studied factors. Then, four VAR compensators (Qc_i) are installed at the four central nodes of the grid. The results of the screening study are shown in Figure 2(b). The length of a bar corresponds to the effect of the considered factor on the voltage in the grid. The higher is the bar associated to a factor, the most influential (and thus efficient) is the factor.

Factors	Node	Unit	Low level	High level
K_1	9-12	/	0.95	1.05
K_2	1-2	/	0.95	1.05
K_3	4-10	/	0.95	1.05
K_4	7-11	/	0.95	1.05
Qc_1	3	Mvars	-10	10
Qc_2	5	Mvars	-10	10
Qc_3	6	Mvars	-10	10
Qc_4	8	Mvars	-10	10

(a)



(b)

Figure 2. Definition of the 8 selected factors and their respective influence on the voltage of the grid for both considered topologies.

Only the two most influential factors (K_1 and Qc_2) are then selected for the optimization. This response is here the sum of the absolute values of the voltage deviations at each node of the network compared to the rated voltage. This response must therefore be minimized. The comparisons between the voltage profiles before and after the optimization for respectively the low and high voltage issues are then presented in Figure 3(a) and 3(b).

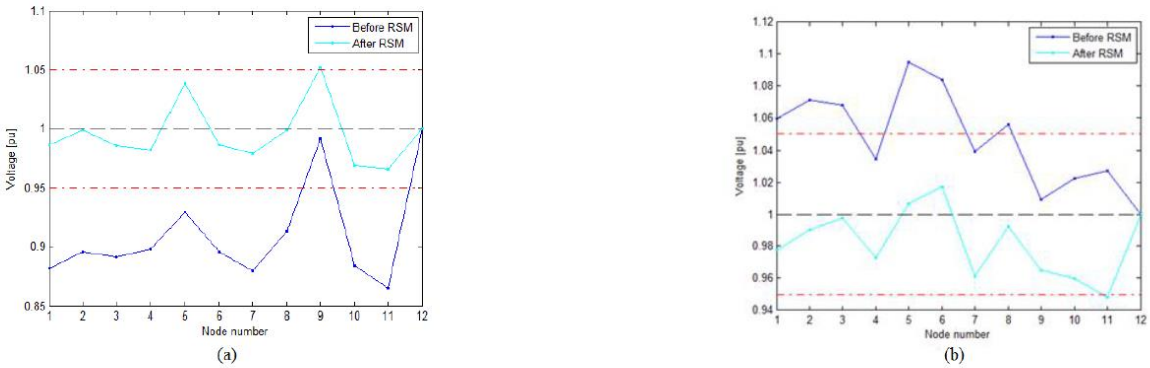


Figure 3. Comparison of the voltage profile before and after the RSM optimization for both voltage issues.

CONCLUSIONS

After both optimizations, the voltage remains in the range of its allowed values ([0.95 pu, 1.05 pu]) which was the searched objective. For the future, it will be interesting to focus not only on the voltage profile but to consider also the power losses and the possibility of line congestion and thus to head for a multiobjective approach.

MAIN REFERENCES

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[2] P. N. Vovos, «Centralized and distributed voltage control : impact on distributed generation penetration », IEEE Transactions on Power Systems, vol. 22, no. 1, 476-483.