VOLTAGE CONTROL AND REACTIVE POWER MANAGEMENT IN THE DAY-AHEAD ELECTRICITY MARKET

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Abstract - The liberalization of the electricity market has brought forward the need of the Independent System Operator (ISO) to take into consideration different criteria when optimizing the performances of the transmission network. This paper presents a multiobjective optimization approach applied to the Romanian power grid in the presence of the hierarchical voltage control.

Keywords: hierarchical voltage control, electricity market, multiobjective optimization.

1. Introduction

The economic and technical changes induced by the electricity market in the operation of power systems have lead to a change in the duties of the former dispatcher, which is now an Independent System Operator (ISO). The actions carried out by the ISO in order to optimize the electric grid have to take into account many different aspects correlated with the secure and efficient operation of the system.

Minimizing the total active power losses in the grid can no longer be considered the only objective as attention has to be paid to the dispatching of reactive power resources and the operation of the lines closer and closer to their thermal limit has made system security a pressing issue. The use of Multiobjective Optimization (MO) techniques gives the system operator a tool for the decision-making process, offering an infinite number of possible operating point from which one can be chosen according to the relative importance given to the different objective functions [1].

In this paper the results of a multiobjective optimization carried out on a model of the Romanian power grid in the presence of the hierarchical voltage control is presented. One, two and three objective functions are used and the result are discussed in correlation with the voltage profiles obtained for the pilot bus voltages.

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The characteristics of each zone in terms of reactive power generation/consumption and reactive power resources are used to explain the behaviour observed. The results are compared to the ones obtained for a model in which only the primary voltage control is implemented.

2. Objective functions and the mathematical model

Three objective functions were chosen for this paper :

1. Minimizing the active power losses in the network. As in the day-ahead market the active power generated/consumed at each node is known, minimizing the active power losses is equivalent to minimizing the active power injected by the slack bus. This method is being used by ISOs worldwide as a way of reducing the overall cost of losses in the network.

$$\min \Delta P = \min \sum_{node} P_{node} = \min P_{slack\_bus} \tag{1}$$

2. Minimizing the total reactive power produced/absorbed by the generators. This objective function is intended to maintain a reasonable reactive power supply at the generators to be used in case of a contingency in the network. In this paper the minimization of the square of the reactive power injected by the generators was adopted.

$$\min \sum_{j=1}^{n} \left| Q_{gj} \right| \to \min \sum_{j=1}^{n} Q_{gj}^{\ 2} \tag{2}$$

3. Maximizing the λ (loadability) factor seen as the distance from the current operating point and the collapse point on the PV curve with constraints being imposed on the bus voltages. The lambda factor is correlated with the security of the network and its maximization is intended to give a wide margin for the increase of the load in the network.

$$\max[\lambda]; P_{(0)}, Q_{(0)} \to P_{(\lambda)}, Q_{(\lambda)} \tag{3}$$

The mathematical model for the hierarchical voltage control contains 5 types of busses [2] and for a system optimization the pilot bus voltages are considered here as independent variables.

The model used for the determination of the maximum value of lambda [3] is realistic and an be divided in two cases : one in which the pilot bus voltages are maintained constant between the base and critical load flow and one in which the pilot bus voltages are allowed to decrease in the critical load flow.

The mathematical model was implemented in GAMS [4] which used the solver MUMPS for the problem.

3. Database used

The database used for this study is composed of 287 busses and 450 branches and represents a reduced model of the Romanian electric grid. It is composed of the 400 kV and 220 kV networks and some 110kV/medium voltage nodes.

When the partitioning of the grid in areas for the secondary voltage control was done [5] the optimal number of zones was determined to be 6.

In figure 1 the extent of each area is shown. The black dots represent pilot busses and the green rectangles control generators. Also, in table 1 the characteristics of each area are presented.

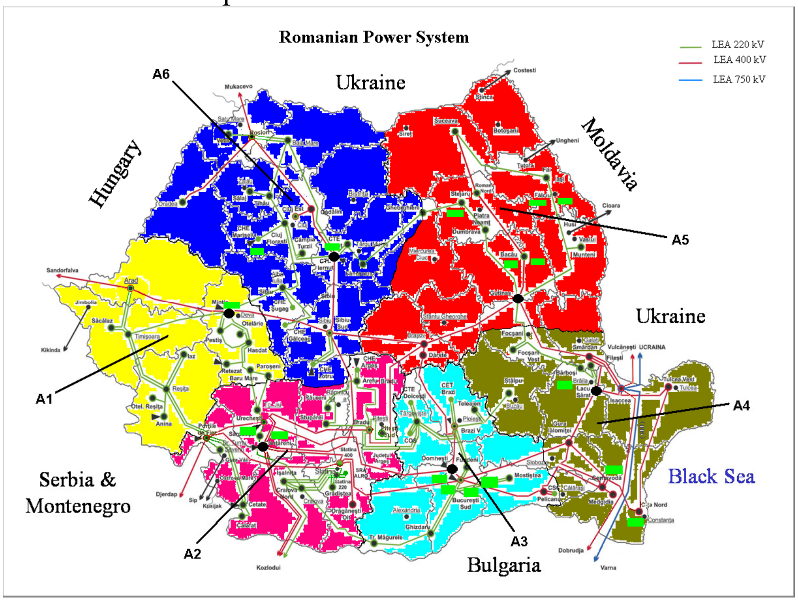


Fig.1. The partitioning of the Romanian power grid

Table 1

Characteristics of each area of the secondary voltage control

zone	Generated active power (whithout the slack bus generator) [MW]	Total active power available at the generators(without the slack bus generator) [MW]	Demanded active power [MW]
1	720	1094	816.21
2	3310	4727.9	1847.26
3	630	749	1291.95
4	1105	1176	1108.95
5	451	627.4	1074.65
6	540	877.4	821.65

zone	Reactive power reserves at control generators[MVAr]	Reactive power reserves at generators(without the slack bus generator) [MVAr]	Demanded reactive power [MVAr]
1	436.8	551.2	173.03
2	832.4	2109.2	723.87
3	289.7	488.6	255.59
4	516.7	666.5	484.17
5	336.3	397.3	337.81
6	243.21	474.21	336.77

Area 2 is characterized by the presence of big coal-fired plants and produces about half of all the generated active power , therefore it has the biggest reactive power reserves and also the biggest active/reactive consumption. Area 1 has a very low reactive power demand while area 6 has a deficit of reactive power supply for the secondary voltage control compared to it's size and topology.

Area 5 has virtually every generator participating at the secondary voltage control.

Concerning the determination of lambda, it can be seen that the areas which will have the biggest production increase are areas 2, 1 and 6. Areas 3 and 5 will have a more moderate production increase, while area 4 will have practically no production increase (compared to the generation in the initial operation point).

4. Results

The results on the model that contains just the primary voltage control are shown in table 2.In this case the only possible operating point is characterized by the following values for the three objective functions. The base power considered in this paper is 280 MW and all the results are reported to this power.

Table 2

Results for the primary voltage control

Objective function	Value
Active power injected by the slack bus (P_slack) [p.u.]	2.508
Total reactive power injected by the generators (Q_tot) [(p.u.)^2]	2.786
Lambda [max.]	0.189
Active power losses [p.u.]	0.490

As for the model with the hierarchical voltage control implemented, the optimization of each objective function results in a different operating point and is characterized by the following values (Table 3):

Table 3

Results for the hierarchical voltage control

Objective function	Active power injection at the slack bus (P_slack) [p.u.]	Total reactive power injected by the generators (Q_tot) [(p.u.)^2]	Lambda [max.] -	Active power losses [p.u.]
[MIN]P_slack	2.47239	3.20179	-	0.45496
[MIN]Q_tot	2.50426	2.02415	-	0.48684

[MAX]lambda – model 1	2.48794	3.89925	0.26702	0.47051
[MAX]lambda – model 2	2.48308	3.275	0.33873	0.46565

Minimizing the total reactive power injected results in high active power losses, while maximizing the loadability factor (λ) needs high reactive support by the generators.

A look at the voltage profiles at the pilot nodes can give a better understanding of the data given by Table 3. Figure 1 shows the voltage profiles of the pilot nodes for the different objective functions. The results are in p.u. and the base voltage of all the pilot busses in 400 kV.

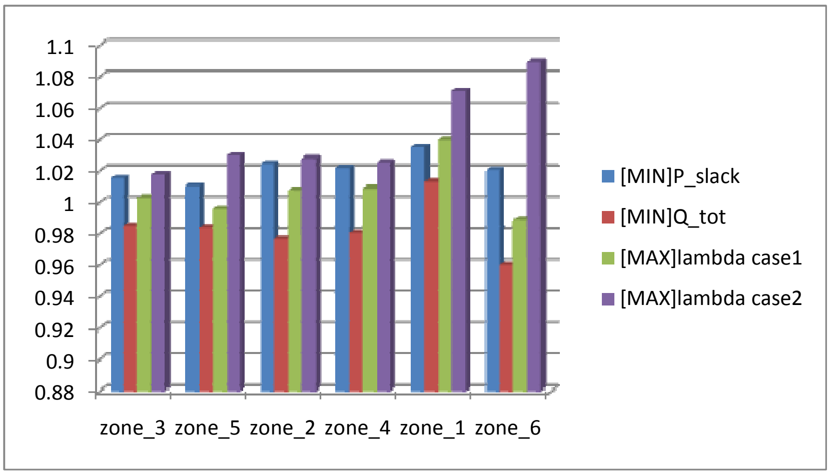


Fig. 1. The voltage profile of the pilot nodes for the different objective functions

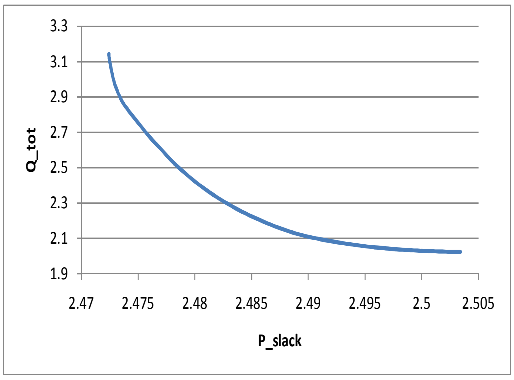
As it was expected, minimizing the reactive power injected by the generators results in low voltages in the pilot busses and consequently throughout the network.

The minimization of active power losses requires higher voltages and therefore more reactive power being injected by the generators.

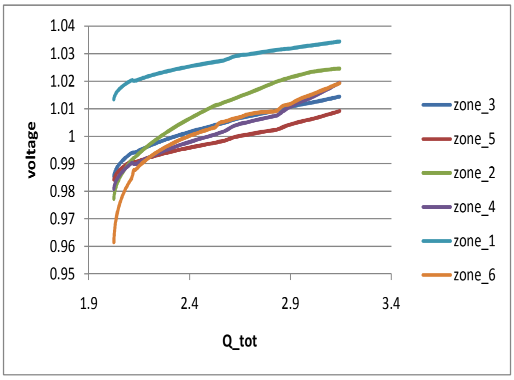
Maximizing the lambda factor requires different voltage profiles for the two cases. In the case in which the pilot bus voltage is maintained constant in the base and critical load flow lower voltage values are required. This is because these are the maximum voltages that can be kept constant between the base and critical load flow. When the pilot bus voltages are allowed to decrease in the critical load flow, higher voltages are obtained and the loadability factor increases substantially.

In the multiobjective optimization only the second case will be taken into account as it improves the value of lambda and it's results are more closely related to the actual evolution of voltages in a network when a load ramp is applied.

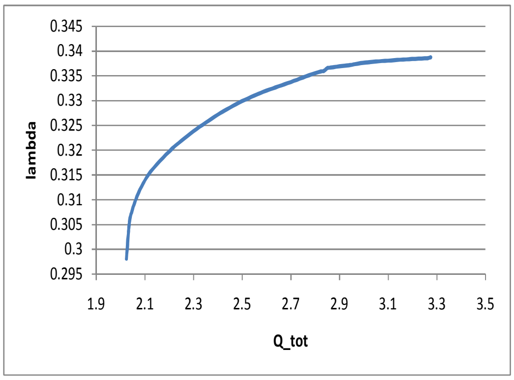
Moving on to the multiobjective approach using two objective functions, the curves of possible operating points for the three combinations of objective functions are given in Figure 2. Also the evolution of the pilot bus voltages are given.



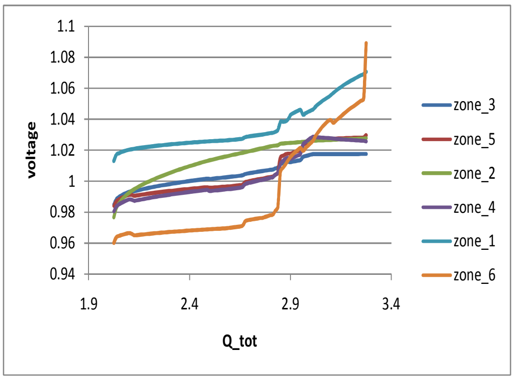
2.1a.



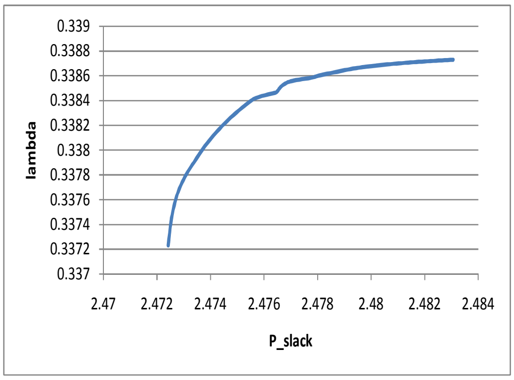
2.1b.



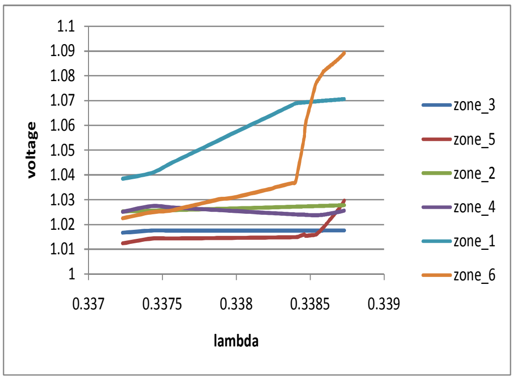
2.2a.



2.2b.



2.3a.



2.3b.

Fig. 2. 2.1a,b – Multiobjective [P_slack, Q_tot] and the evolution of pilot bus voltages
2.2a,b – Multiobjective [lambda, Q_tot] and the evolution of pilot bus voltages
2.3a,b - Multiobjective [lambda, P_slack] and the evolution of pilot bus voltages

Figures show 2.1 b and 2.2 b that both minimizing the active power losses and maximizing the lambda factor require substantially higher voltages then minimizing the total reactive power injected by the generators.

The discontinuities observed in the evolution of the pilot bus voltages when determining the possible operating point are determined by the discontinuous way in which the generators not participating at the secondary voltage control are modeled. In each of these points one generator modeled as a PV bus looses or reenters it's reactive power output capability.

As it can be seen from figure 2.3a, as long as the reactive power output is not considered as a criteria for the optimization, active power losses remain low and the lambda factor is very high throughout the curve of possible operating points. High pilot bus voltages are advantageous both from the perspective of minimizing the active power losses and maximizing lambda and therefore these two objective functions are not necessarily in conflict.

Even the lowest value obtained for lambda (≈ 0.29) is one that gives a wide margin for the increase of power transmitted throughout the network and therefore we can say that the system with this particular partitioning is a very robust one.

When we use three objective functions the multiobjective curve turns into a surface, which is presented in figure 3.

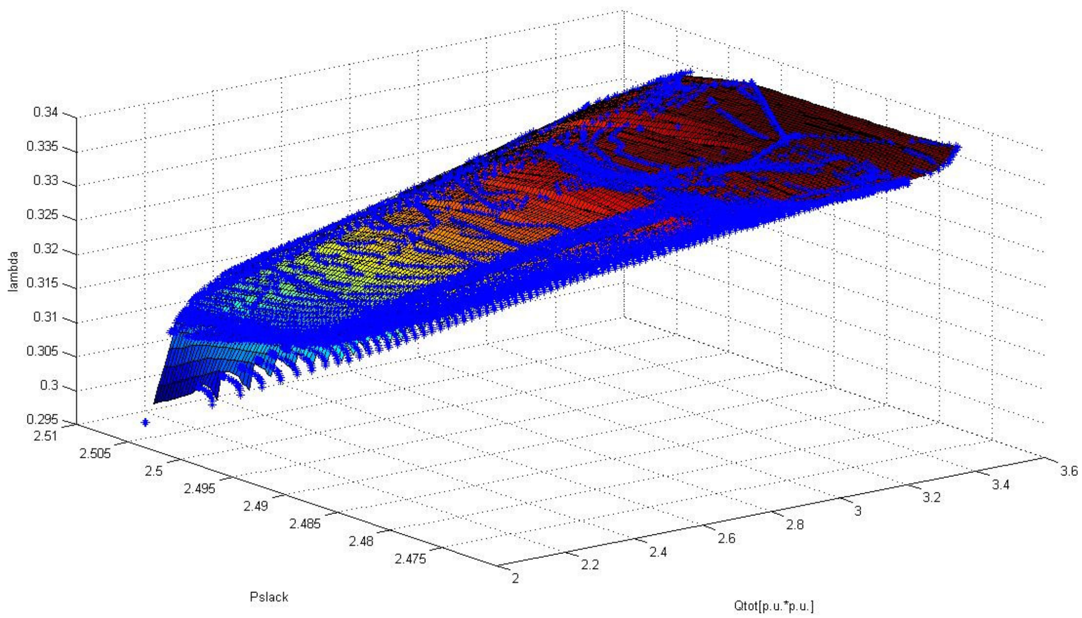


Fig.3.The surface of possible operating points using three objective functions

The colors refer to the values of lambda : blue means the lowest values, red the highest ones.

It can be seen that for big reactive support from the generators the lambda factor is quite large and the active power losses can have small values.

On the contrary, when we go towards minimizing the total reactive power produced/absorbed by the generators the number of point from which we can choose for an operating point diminishes and the other two objective functions have unsatisfactory values.

The surface presents a flat area at the top; here two objective functions can be used instead of three as lambda has an almost constant value in this region.

6. Conclusions

In this paper the results of a multiobjective optimization applied to the Romanian power system is presented. The results give the ISO a tool for choosing an operating point that represents a trade-off between the different objectives involved in a market environment. Reactive production at the generators influences substantially the pilot bus voltage profiles and is in a strong conflict with the other objective functions.

Minimizing the active power losses and maximizing lambda are not particularly in conflict as long as the pilot bus voltages are maintained at a high level.

In this particular system the loadability factor is very high and the security of the network is practically assured. However, tripping of certain lines must be tested to make sure this is the case in all conceivable situations.

Using three or two objective functions has the advantage of graphically representing the results and making the decision-making process easier. As a lot more objective functions can be conceived, for the use of more then three objective functions a goal-setting method can be more suitable.

R E F E R E N C E S

[1]. *A. Berizzi, C. Bovo, M. Innorta, P. Marannino* , “Multiobjective optimization techniques applied to modern power systems”, Power Engineering Society Winter Meeting, 2001. IEEE.

[2]. *A. Berizzi, C. Bovo, M. Delfanti, M. Merlo, F. Tortello* , “Singular Value Decomposition for an OPRF formulation in presence of SVR”, Electrotechnical Conference “MELECON 2006”, IEEE Mediterranean.

[3]. *V.Ilea, C. Bovo, M. Merlo, A. Berizzi, M. Eremia* “Reactive Power Flow Optimization in the presence of Secondary Voltage Control “, IEEE PowerTech, Bucharest, Romania, 2009

[4]. *R. E. Rosenthal* – “GAMS, a users guide” www.gams.com

[5]. *Andreea Erbasu, A. Berizzi, M. Eremia, C. Bulac* , “Implementation studies of Secondary Voltage Control on the Romanian power grid”, IEEE PowerTech, Saint Petersburg, Russia, 2005