Generator voltages control in real-time and voltage-reactive states on interconnected lines

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Abstract

This paper presents the possible effects of application in real-time advanced method for fast and sufficiently accurate definition of generator voltages to realize the favorable voltage-reactive states of electric power interconnection. The application in real-time will be realized by use of the results of state estimation, which is the part of the new SCADA/EMS system in NDC (National Dispatching Center) Elektromreža Srbije. The special part of method developed is the possibility to make the direct connection between the values of generator voltages and voltage-reactive states on interconnected lines. The verification of method proposed is made on the examples of perspective states of Serbian transmission network, in own wide environment.

Introduction I

An important problem in modern Electric Power Systems (EPS's) is the provision of the necessary level of operational security. In recent years, the increased practical interest to these issues has been shown and corresponding new challenges appeared, mainly due to increased loading of EPS's, combined with a process of deregulation in electric power market and restructuring of the power utilities. In this context, the voltage-reactive power problem plays an essential significant role.

Also, the processes mentioned above, are very important and topical for all countries in Southeast Europe, as well as for Serbia and its electric power industry, in accordance with:

- Reconnection of the Second UCTE synchronous zone with the main part of the UCTE grid, which was successfully made in 10th October 2004.
- Establishment of Regional Electricity Market in Southeast Europe, according to the Memorandum of Understanding
- Obligation to satisfy the requirements, standards and criterions of UCTE, in area, among many another's, of Voltage Control and Reactive Power Management

Introduction II

In context of many activities of evaluation the before mentioned new relevant aspects, is the operational study, which is made by Nikola Tesla Institute for Serbian TSO - Elektromreža Srbije. From a large number of characteristic results obtained, a fact is established about the great influence of adequate choice of generator voltages on established voltage - reactive states of Serbian transmission network.

Also, a practical application of a simple method for improvement of voltage-reactive states in transmission networks by generator voltages control was developed. The verification of this method was made in context of steady-state and dynamic simulation models, on the example of realized and perspective states of Serbian transmission network, in own wide environment.

The application in real - time in future will be realized by use of the results of state estimation, which is the part of the new SCADA/ EMS system in NDC (National Dispatching Center) Elektromreža Srbije. The first practical experiences of the possibility of the application in real-time, has been established also on the model of real interconnection, in which the EPS of Serbia participates.

Introduction III

The basic objective of this paper is to present some advantages of method mentioned before. Those advantages are primarily applied on monitoring and control of the reactive power flow on interconnected lines, according to forming the direct connection between the values of generator voltages and voltage - reactive states on interconnected lines. Also, the evaluation of series favorable technical effects after the generator voltages control belongs to those advantages.

The evaluation and verification of method proposed are made in context of steady - state simulation models, on the examples of perspective states of Serbian transmission network, in own wide environment.

Formulation of the advanced method

The main objective of this paper is the voltage-reactive power problem, e. g. the subject of primarily interest are the processes in so called Q-V contour. However, the processes in so called P-δ contour are not neglected. Those processes are not dominating, but they exist, in very small intensity, after the generator voltage changes.

For steady-state of electric power interconnection, it was necessary to find out a good practical measure of sensitivity change of reactive power of all generators in EPS of interest, caused by change of voltage on selected generators. For this purpose, the following linearized matrix equation is formulated, which gives a good practical measure of sensitivity mentioned above:

$$\Delta Q_G = \frac{\partial Q_G}{\partial V_G} \Delta V_G$$

The order of this matrix equation is extended (relative to initial version of method) for opserved interconnected lines. Thus, order of matrix equation is obtained after Gaussian elimination of all consumers nodes, except the boundary nodes in EPS of interest and elimination of all generators nodes, which are not located in EPS.

Formulation of the advanced method

In opposite problem definition, in context of proposed advanced method, the corresponding linearized matrix equation, of order $N_{GI} + N_{ID}$ is formulated:

$$\Delta V_G = \left(\frac{\partial Q_G}{\partial V_G} \right)^{-1} \Delta Q_G$$

which gives a good practical measure of sensitivity of necessary change of all generator voltages, for correction of reactive power which is asked for, on selected generators and/or selected interconnected lines.

Thus, applying this matrix equation after specification required correction of reactive powers of selected generators, and/or selected interconnected lines (definition the corresponding elements of vector ΔQ_G), the necessary correction of generator voltage ΔV_G is obtained.

Computer program VOLTCONT

On the base of the presented approach, a modularly organized computer program named VOLTCONT (VOLTages CONTrol) is developed. This computer program can analyze the interconnection with 10000 nodes, 30000 lines, 2000 generators and 4000 transformers. User can load input data from UCTE format exchange files or PTI raw format files, using import/export utility.

This computer program consists of the following relevant parts :

- Two procedures for initialization of steady-state security analyses, e.g. the procedures for solving the initial load-flows problem (for given initial generators scheduling in interconnection considered and in conditions of realization of a set bilateral or multilateral exchange programs between EPS’s in interconnection considered)
- These procedures are fully consistent with the specially developed method for the following steady-state security analyses
- The limits of generator reactive power are not constant but rather corresponding functions of relevant generator parameters and state variables

Application of proposed method

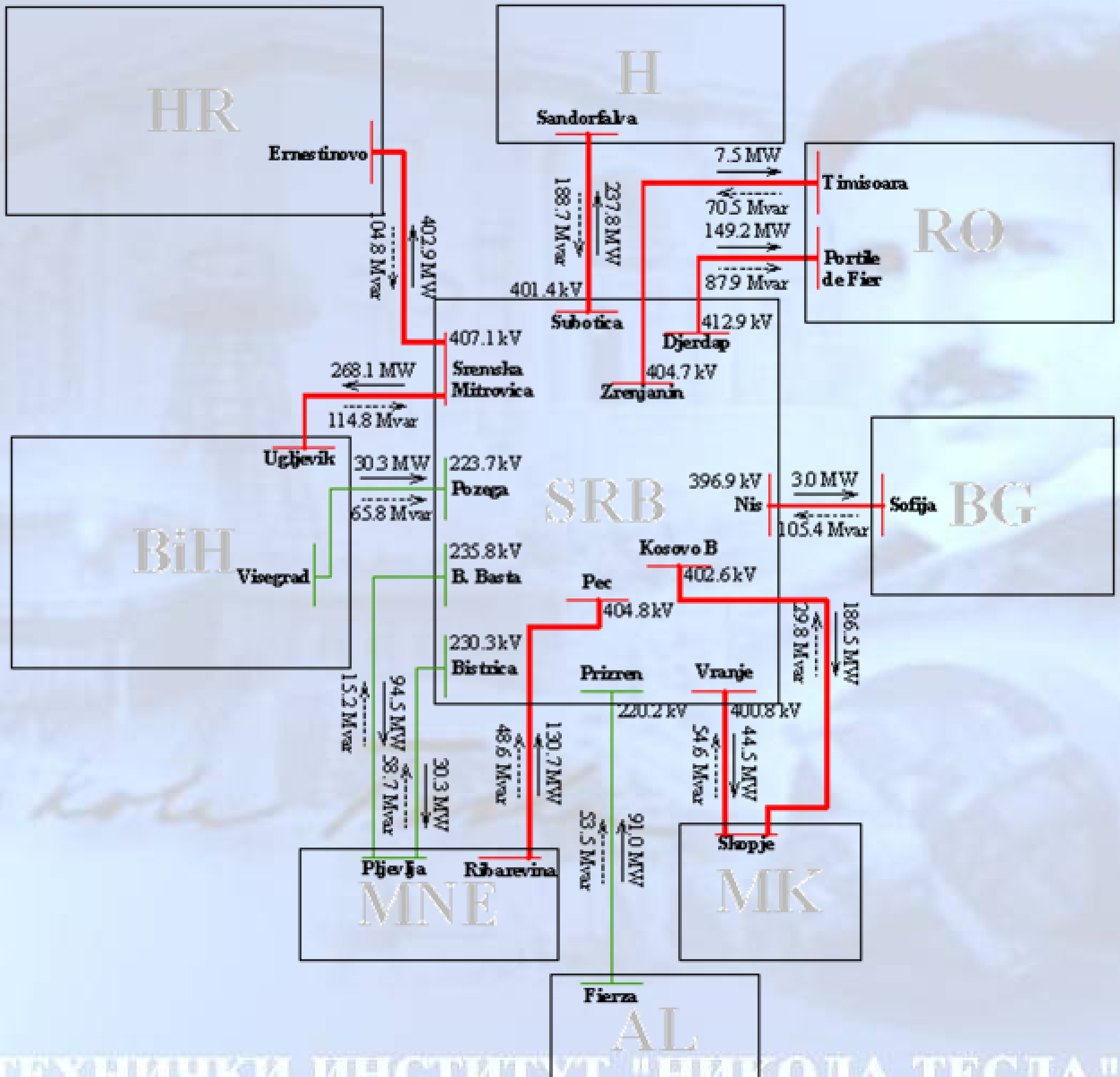
The characteristics and possibilities of advanced method proposed (e.g. computer program *VOLTCONT*), have been established on example of real electric power interconnection, which consists of the EPSs of :

Serbia (SRB), Montenegro (MNE), Bosnia and Herzegovina (BiH), Macedonia (MK), Hungary (H), Croatia (HR), Romania (RO), Bulgaria (BG), Greece (GR) and Albania (AL).

All 400 kV and 220 kV networks of SRB (including 110 kV network), MNE, H, HR, BiH, RO, BG, MK were modeled, as well as the complete 220 kV network of AL. The EPS of GR was represented by a corresponding equivalent at the 400 kV and 150 kV levels, with the exception of the Northern part, which was modeled in detail.

As illustration, following figure shows the block diagram of examined interconnection (which has 1110 nodes), with the active and reactive power flows (MW/Mvar) on interconnected lines and voltages on boundary nodes of Serbian EPS, for expected peak-load conditions for the year 2015.

The active and reactive power flows on interconnected lines and voltages on boundary nodes of Serbian EPS



Application of proposed method

To apply the method proposed, in condition of whole interconnection considered, it was necessary to made the Gaussian elimination of 1066 nodes (90 generator nodes and 976 so called "consumer" nodes). The initial number of nodes was 1110. Thus, the problem will be reduced on 44 (32+12) nodes ($N_{GI}+N_{IL}$). Thus, the number 44 is equal to the number of generators (32) and interconnected lines in operation (12) in Serbian EPS. In this case, for successful application of method, it will be needed to know all necessary data (topology, voltages, active and reactive power injections), not only for Serbian EPS, but also for all neighbors EPS.

However, if the results of state estimation will be used, for successful application of method, it will be necessary to know the data for only 443 nodes (the total number of nodes in Serbian EPS, which includes the boundary nodes). In those conditions, the elimination of only 399 nodes will be necessary. The problem will be also reduced on 44 nodes (equal to the number of generators and tie-lines, which are in operation in Serbian EPS).

Elektrane	Interkonektivni dalekovodi				
	Ugljevik - S. Mitrovica	Ernestinovo - S. Mitrovica	Šandorfalva - Subotica	Sofija - Niš	Portile de Fier - Đerdap
TE Kolubara B	-2.907	-2.097	-1.722	-1.705	-1.586
TE Nikola Tesla B1,2	-7.849	-5.662	-4.597	-0.761	-1.996
TE Nikola Tesla B3	-3.913	-2.821	-2.280	-0.378	-0.999
TE Nikola Tesla A5,6	-4.227	-3.049	-2.504	-0.519	-1.355
TE Drmno	-1.278	-0.922	-1.020	-0.290	-11.588
HE Đerdap 1	-0.046	-0.033	-0.035	-0.433	-166.759

The selected off-diagonal elements of sensitivity matrix $\partial Q_G/\partial V_G$

R.br.	Elektrana, odnosno interkonektivni dalekovod	Q_{GO} (Mvar)	$Q_{GK}=Q_{GR}$ (Mvar)	Q_G (Mvar)	ΔQ_G (%)
1	TE Kolubara B 1, 2	124.3	189.5	186.4	1.663
2	TE N.Tesla B1, 2	123.5	245.2	241	1.743
3	TE N.Tesla B 3	102.1	164.4	161.2	1.985
4	TE N.Tesla A 1, 2	210.3	197.6	195.9	0.868
5	TE N.Tesla A 3, 4	269.4	253.4	251.3	0.836
6	TE N.Tesla A 5, 6	229.7	180.2	177.7	1.407
7	TE Drmno	124.5	110.1	107.8	2.134
8	S.Mitrovica-Ugljevik	-114.8	-85.5	-82.3	3.888
9	S.Mitrovica-Ernestinovo	-104.8	-83.8	-81.4	2.948
10	Subotica-Šandorfalva	-188.7	-171.4	-167.9	2.085
11	Niš-Sofija	-105.4	-99.5	-98.5	1.015

The effects of generator voltages control in TPP Kolubara B1, 2, TPP N. Tesla B1, 2 and TPP N. Tesla B3

Conclusion

This paper presents a possible way to form a simple and efficient generator voltages control method. The development of this method is inspired by known fact of great influence of adequate choice of generator voltages on established voltage-reactive states. The relevant part of this method is the possibility to monitoring and control the reactive power flows on interconnected lines.

Apart from its simplicity, the method is characterized by sufficient accuracy, which was demonstrated on the example of real electric power interconnection, which consists of the EPS's of Serbia, Montenegro, Hungary, Croatia, Bosnia and Herzegovina, Romania, Bulgaria, Macedonia, Greece and Albania.

Therefore, the method (e.g. computer program VOLTCONT) presented can be regarded as a useful addition to the software support of operational planning, as an integral part of EMS of Serbian TSO. The application in real- time in future will be realized by state estimation, which is the part of the new SCADA/EMS system in NDC Elektromreža Srbije.

Thank you for your attention