51. IWK

Internationales Wissenschaftliches Kolloquium
International Scientific Colloquium

PROCEEDINGS

11-15 September 2006

FACULTY OF ELECTRICAL ENGINEERING AND INFORMATION SCIENCE

INFORMATION TECHNOLOGY AND ELECTRICAL ENGINEERING - DEVICES AND SYSTEMS, MATERIALS AND TECHNOLOGIES FOR THE FUTURE

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=12391

TECHNISCHE UNIVERSITÄT
ILMENAU

Impressum

Herausgeber: Der Rektor der Technischen Universität Ilmenau
Univ.-Prof. Dr. rer. nat. habil. Peter Scharff

Redaktion: Referat Marketing und Studentische Angelegenheiten
Andrea Schneider

Fakultät für Elektrotechnik und Informationstechnik
Susanne Jakob
Dipl.-Ing. Helge Drumm

Redaktionsschluss: 07. Juli 2006

Technische Realisierung (CD-Rom-Ausgabe):
Institut für Medientechnik an der TU Ilmenau
Dipl.-Ing. Christian Weigel
Dipl.-Ing. Marco Albrecht
Dipl.-Ing. Helge Drumm

Technische Realisierung (Online-Ausgabe):
Universitätsbibliothek Ilmenau
ilmedia
Postfach 10 05 65
98684 Ilmenau

Verlag: isle
Verlag ISLE, Betriebsstätte des ISLE e.V.
Werner-von-Siemens-Str. 16
98693 Ilrnenau

ISBN (Druckausgabe): 3-938843-15-2
ISBN (CD-Rom-Ausgabe): 3-938843-16-0

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=12391

51st Internationales Wissenschaftliches Kolloquium
Technische Universität Ilmenau
September 11 – 15, 2006

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Network congestion identification and elimination measures evaluation in the liberalised electricity markets

Abstract

The paper describes an approach for NTC maximum values definition, estimation of short- and middle term congestion elimination measures and definition of weak elements and congested interfaces. Application of singular analysis for revealing weak places is considered. Economical estimation of the considered measures efficiency is made.

Introduction

Introduction of liberalised electricity market has brought dramatical changes in power system operation modes. Due to different fuel prices, generation structure power flows between some countries have increased or changed its direction mostly from countries with low electricity price. Many ties were not designed for such drastical changes and may be congested. Especially it is critical for cross-border interfaces, at which bottlenecks occur most part or all over the day. Sometimes internal network congestions might take place.

If bottlenecks are regular they should be eliminated. All congestion elimination measures may be subdivided into three groups (short-, middle- and long term) according to the project schedule. This paper considers middle-term measures. Since the measures are complex management decisions or technical solutions and require large volume of financing its efficiency and profitability are to be defined. This requires a complex approach, both technical and commercial, that first defines technical feasibility and than commercial aspects.

Due to initial data uncertainties, its forecasts may be absent or have low reliability, probability parameters must be introduced for both initial data and results obtained.

Experience of market introduction shows electricity price decrease. Congestion management permits further price drop, better load flow scenario, elimination of bottlenecks, better power quality, etc. However for final statement of congestion elimination measures a complex approach is necessary that does not depend on geographical situation, fuel prices, generation and network development, market opening degree etc.

The aim of the study is to develop a method for maximum NTC values calculation of definite cross-border interfaces and to evaluate middle term congestion management measures under certain initial data and forecast values as well as to provide a complex economic estimation of middle term congestion management measures.

Congestion identification

In order to estimate possible congestions in the future, network and generation development as well as fuel prices must be known. This allows preliminary estimation of network operational modes. Optimisation on generation side will provide data for electricity price calculation, forecasts, market running and final calculation of power flows.

Congestions in the future are to be expected at least in the following cases:

- Strong load or installed power increase
- Big fuel price difference between countries or parts of the countries with large power transits
- Significant power plant close-down without new generation capacity commissioning.

As market introduction experience shows, if congestion occurs, almost all transmission lines of the congested cross-section are fully loaded. The fact that future congestions may be predicted or defined by known statistics, forecast values, governmental development programs permit to make preliminary estimation of the congested links.

This paper uses singular analysis for preliminary congestion identification. The method investigates steady state operating condition parameters sensitivity to the initial data variations [1]. It is known that singular values are square roots of eigenvalues λ_i of matrix $A^T A$ and AA^T $[k \times k]$, i.e. $\sigma_i(A) = \sqrt{\lambda_i(A^T A)} = \sqrt{\lambda_i(AA^T)}$, i=1,…,k Load-flow Jacobi matrix can be represented as: $J = W\Sigma V^T = \sum_{i=1}^{k} w_i \sigma_i v_i^T$ (1), where $W = (w_1, w_2, ..., w_k)$, $V = (v_1, v_2, ..., v_k)$ have dimension (kxk) and their $i-th$

columns are correspondingly $i-th$ left and right singular vectors, Σ - diagonal singular values matrix $\Sigma = diag(\sigma_1, \sigma_2, ..., \sigma_k)$. Singular values and corresponding right and left singular vectors provide operating condition variables sensitivity to independent state parameters like active and reactive load and generation power. So, the maximum values of the singular vector components corresponding to the minimum singular values identify weak nodes in the system and maximum difference of the singular vector components defines weak links. At very high loads node voltage values might be well below allowed values, so voltage stability may become a major issue rather than steady state stability. However the results of singular analysis do not reveal what kind of stability problems arise. So when considering large power systems singular analysis finds weak nodes and links and allows further identification of weak cross-sections, probably with congestions.

After weak links identification full (includes only weak links) and partial (some of links are weak) weak cross-sections might be defined. In case there are some partial weak cross-sections, further studies should be made for each case e.g. by means of load flow calculations. Thus, singular analysis gives only qualitative results and is only the first step in congestion identification problem.

The next step is the estimation of congestion elimination means, such as commissioning of new lines, transformers, FACTS devices etc. Singular analysis has to be repeated once again for the reinforced grid. The minimum singular values will increase and maximum values of the singular vector components corresponding to it will decrease in case the reinforcement means are effective.

At the same time the increase in transmission capacity will allow higher tie- and cross-section loading, so the operating mode of the system will be more severe than before reinforcement. This is a result of generation redispatch which is due to new limitations in the optimisation problem. Due to the generation scenario changes some network elements will have bigger power flows. Elements of Jacobi matrix will follow the changes, so both minimum singular values and values of the corresponding singular vector components will change. In this case no definite answer can be given because singular analysis results before and after grid reinforcement may coincide, but power flows will increase thus indicating better network performance. In this case load flow calculations finalise the solution. On its basis NTC values are defined and final statement about NTC increase and congestion elimination measures is made. The results obtained answers what kind of limitation is reached, i.e. voltage or angle stability, permissible heating etc. as well as what elements limit further power transmission increase.

Load-flow calculations should be made for several strategies of initial steady state burdening as well as for different combinations of fuel prices. It is actually a combinatory problem considering all possible load and generation growth scenarios, but from many of them only realistic ones must be chosen. At the same time a dependence of NTC on different parameters of congestion elimination measures can be obtained, e.g. on FACTS installed capacity and allocation.

Last but not least is economical estimation of the congestion elimination methods. In this paper it is based on Net Present Value method [2] showing total costs and savings during the whole operational period. Using this method further parameters dependencies may be obtained: NPV of the total system savings after congestion elimination measure is launched, kWh total costs decrease, savings sensitivity on fuel prices, inflation rate and final customer electricity price.

Another option for such studies is consideration of uncertainties. If initial data are uncertain or have a probabilistic character probability theory should be introduced in both initial data and results estimation. It is reached by means of assigning certain probabilities to both combination of initial data and results obtained. Most often it is load, fuel price and other values.

Studied system and obtained results

As an object for studies united power system of the Urals, Russia is chosen. The equivalent circuit of its grid is shown in Fig. 1.

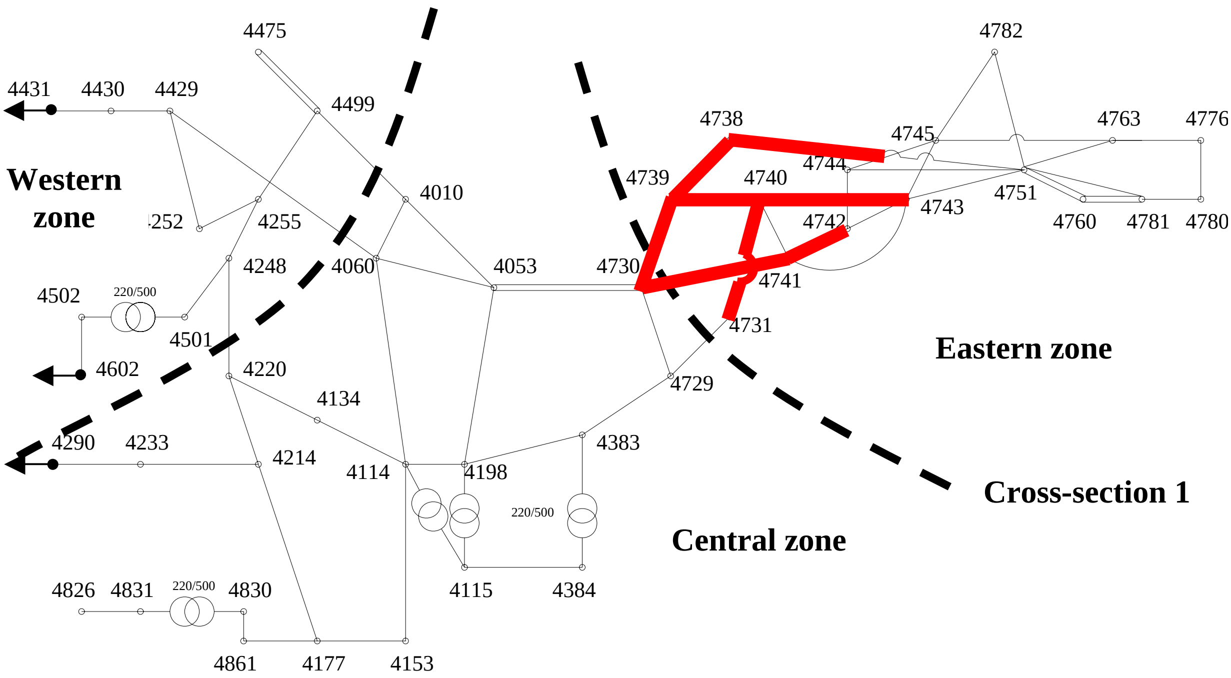

Fig. 1. Studied power system

Initial data for calculations included different fuel prices as well as load values. In the reality there are ties to the neighbouring power systems starting from nodes 4431,4602 and 4290. Power export to the West from the studied system is only possible by these ties. That is why steady state condition burdening was made by a proportional load increase in these nodes. All possible combinations of both fuel prices and load values were calculated. Set of optimisations was performed and the results together with preliminary load flow calculations show the increase in power flows from the eastern zone via central and western zones. Steady state stability limits further power flow increase from Eastern to Western zone, thus revealing congested cross-section.

Application of the singular analysis shows that the weakest lines are 4738-4739, 4738-4751, 4730-4739, 4739-4740, 4731-4740, 4740-4743, 4741-4742, 4741-4743, 4730-4741 (see Fig. 2.). These links will preliminary identify the weakest cross-section consisting of the following lines: 4730-4739, 4730-4741 and 4731-4729 (Fig. 1., Cross-section 1). So there is a need to increase its transmission capacity. As it is seen the weakest cross-section consists not of the three weakest links.

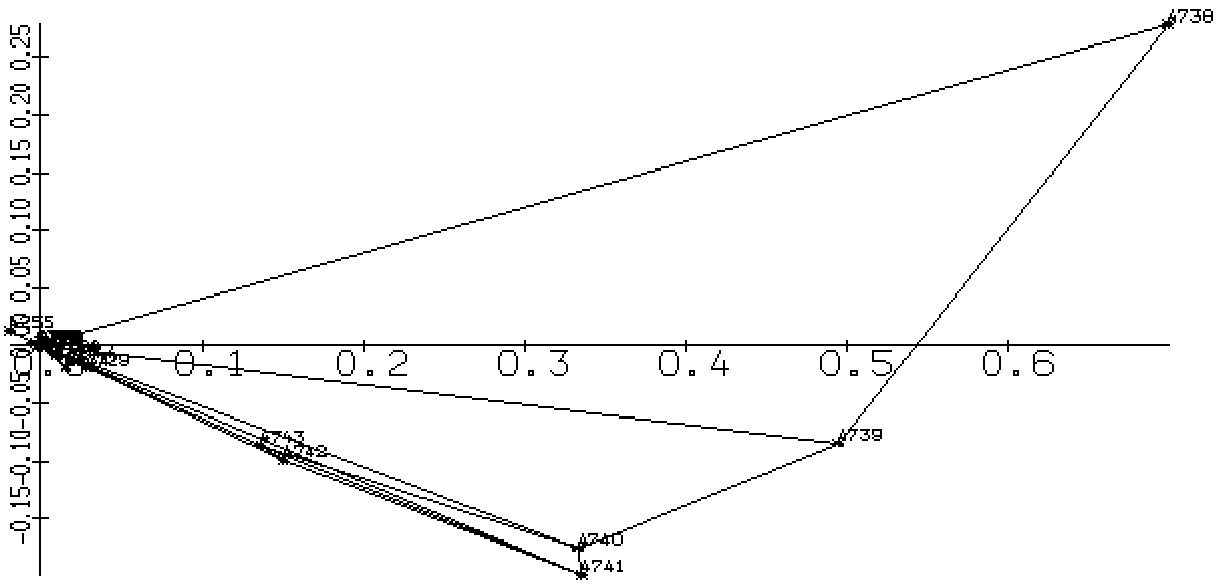

Fig. 2. Network graph in 1-st and 2-nd singular vector coordinates corresponding to the voltage values.

After all weak places and cross-sections in the system were fully identified and it was stated that transmission capacity is to be increased, congestion management measures were introduced and its technical and economical effects were estimated. After FACTS installation new optimisation was made and it has been shown that all considered FACTS increase transfer capacity of cross-section 1. Following FACTS devices were studied:

- 50, 100 and 150 MVAr SVCs in nodes 4740, 4741, 4731.
- SC in line 4730-4741 (compensation degree from 0,1 to 0,5)
- SC in parallel lines 4729-4731 and 4730-4739 (compensation degree from 0,1 to 0,5)

From singular analysis point of view, minimum singular values changed from 0,26049 in former system to 0,35617 and 0,40646 depending on load increase in node 4290 (correspondingly 1200 MW and 2300 MW).

Theoretically the values must be reduced but the results are affected by generation redispatch that proves that minimum singular value may increase for some systems resulting from generation redispatch. At the same time main estimation criterion is a ratio of maximum singular vector component to minimum singular value (Ratio ***A***). In this case this ratio has changed from 0,0187 in the former system to 0,01367 at 1200

MW and 0,06966 at 2300 MW load increase in node 4290.

Introduction of SC with 10% compensation in line 4730-4741 increases minimum singular value from 0,12966 to 0,14411. Load increase to 2300 MW in node 4290 increases Ratio ***A*** from 0,12113 to 0,15591 that indicates that the system is more heavily loaded. The change in SC compensation degree from 0,1 up to 0,5 shows that minimum singular value increases up to compensation level of 0,25-0,3 and further increase is negligible (saturation). This means that from technical point of view SC compensation degree above 0,3 is not effective. Thus by the method used in this paper one can easily choose and estimate effectiveness of the congestion management measures from the technical point of view. Same singular analysis studies were made for SC in two parallel lines 4729-4731 and 4730-4739 (Table 1). The results obtained are principally the same except that no saturation was observed. The only difference is that at compensation degree increase in lines 4729-4731 and 4730-4739 Ratio ***A*** is growing instead of expecting decrease. This is due to the generation redispatch. It will be shown later that power transfer will increase with the growth in Ratio ***A***, and this ratio can be considered as an index of operating conditions proximity to the stability limit.

Table 1. Values of Ratio ***A*** for various values of compensation degree

Compensation degree		In line 4730-4739				
		0,1	0,2	0,3	0,4	0,5
In line 4731-4729	0,1	4,550	4,794	5,141	5,662	6,532
	0,2	4,798	5,086	5,519	6,136	7,223
	0,3	4,980	5,482	6,123	7,174	8,251
	0,4	5,596	6,129	6,993	7,796	11,051
	0,5	7,953	8,763	11,140	13,982	17,162

At the last step in the load flow calculations were performed for the system with FACTS installed. As was expected FACTS installation results in additional transfer capacity and its increase is proportional to the FACTS capacity. For the considered system transfer capacity increase coefficient $K_{TC}^{incr} = \frac{\Delta P}{Q_{FACTS}^{installed}}, \left[{MW}/{MVAr} \right]$ is in the range from 0,46 to 0,66 depending on the type and installed capacity of the device. The limitation in all the calculations was due to steady state stability limit. In case of two SCs in lines 4729-4731 and 4730-4739 the transfer capacity increase is shown in the Table 2.

Table 2. Cross-section 1 NTC value increase with SC in lines 4729-4731 and 4730-4739

		SC compensation degree in line 4730-4739				
		0,1	0,2	0,3	0,4	0,5
SC compensation degree in line 4729-4731	0,1	30	42	74	98	121
	0,2	52	72	88	113	142
	0,3	63	88	101	131	179
	0,4	89	107	124	143	199
	0,5	113	124	147	169	220

The results show that singular analysis have to be supplemented with load flow calculations results, otherwise it may be interpretation wrongly. It is obvious that though Ratio ***A*** is increasing with the SC compensation degree increase due to generation redispatching NTC value will also increase that indicates better network performance from electricity market point of view.

The final step was economic evaluation of FACTS using Net Present Value method. Main parameters of interest were IRR and profit value after 30 years of FACTS exploitation. Calculations shown that SVCs IRR are between 7 and 15 years depending on allocation and installed capacity. For the system considered SVCs with less than 50 MVAr installed capacity may become unprofitable in future. NPV values are in the range from negative to 10 million Euros in 30 years). Same calculations for SC gave IRR in the range between 2 and 5 years. and much higher NPV values (some hundred million Euros in 30 years). Generally from in terms of economics SVCs are not very profitable measure for cross-border NTC value increase. SC devices are up to two times more profitable than SVCs both technically and economically.

Conclusion

Studies made and obtained results permit to state that congestion management problem can be analysed in two steps using singular analysis and load flow calculations. First step – singular analysis allows for preliminary congestion identification. Second step is load flow calculations determining NTC values, technical limitations, as well as economical estimation.

In order to evaluate congestion management measures, e.g. FACTS, the calculations should be performed for system without and with FACTS and quantitatively compared. As a result of such studies probable economy on generation, transmission and distribution side can be found.

When applying singular analysis Jacobi matrix J is to be analysed. For adequate results of the comparison the same dimension of J must be maintained i.e. the same number of nodes and branches in the network. If generation redispatch and FACTS are considered at the same time singular analysis can show grid is getting weaker but in this case system operational mode might be much more severe than in the former system without generation redispatch. The weakest branch or node may not be the most critical element in the system especially when cross-border ties and cross-sections are considered. When the weakest cross-section is being found all weakest branches found by singular analysis must be taken into consideration. The weakest branch will not always be a part of the weakest cross-section as well as the weakest cross-section will not always consist of the weakest links.

A method for maximum transfer capacity values estimation and FACTS efficiency evaluation is suggested based on singular analysis and load flow calculations. Results obtained show that FACTS increase NTC values proportionally to the device installed capacity with transfer capacity increase coefficient of about 0,5. The approach is also suitable for sensitivity studies to the fuel prices, inflation rate (bank interest rate) and load development.

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