A method for total transfer capability estimation for generation of a trade-off solution on using available transfer capability of the controlled cutsets

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***Abstract* — The paper solves the problem of calculation of available transfer capability of the controlled cutsets on the basis of the results of the methods of state estimation and total transfer capability estimation. The decentralized calculation of the total transfer capability values that are applied for generation of a trade-off solution on additional loading of the controlled cutsets is suggested. The technique of calculating the total and available transfer capabilities and the control actions intended for using the available transfer capability is described in detail. The method is illustrated by the example of calculating the total and available transfer capabilities of different controlled cutsets of a real electric power system.**

***Index Terms* — Available transfer capability, trade-off solution, total transfer capability, state estimation, electric power system.**

I. INTRODUCTION

The maximum use of the transfer capability of cutsets is important from the standpoint of the effective control of electric power system (EPS) states. The transfer capability of cutsets can be divided into two components: reserved and available. The reserved part of the transfer capability is determined by the long-term contracts on power supply. The available part is distributed on the short-term basis and is called the available transfer capability (ATC). The ATC value is a very important information for market control from the technical and economic standpoints. Overestimation of ATCs leads to overloading of cutsets and hence, to electric power system reliability loss. Underestimation of ATCs decreases effectiveness of market operation. ATC is the power that can be transmitted in the cutset above the reserved power, i.e. after the existing commitments to consumers are fulfilled [1, 2, 3]. ATC is calculated as a difference between the values of the total transfer capability (TTC) that is calculated in terms of the reliability criterion and power flow in the current system state. The correct calculation of ATC of the controlled cutsets can be obtained by determination of TTC of these cutsets.

TTC is determined by a great number of devised methods, such as: the equations of limiting conditions [4], search for the saddle point based on the generalized Newton method [5], optimal power flow (OPF) methods [6]–[10], methods of repeated power flows [11]–[16], method of analysis of power transfer distribution factors (PTDF) [17]–[20], continuous power flow (CPF) method [21], [22].

Competitive electricity market generates the need to apply a trade-off approach to determination of the maximum admissible loading of equipment [23] and to calculation of TTC and ATC of the controlled cutsets. The use of ATC of cutsets suggests a change in system states due to an extra loading of these cutsets. Obtaining the desired states is no easy task, since it is necessary to control load of several indicated cutsets and take into account the states of an adjacent network. In the case of ATC calculation of several cursets this problem gets more complicated, by that several operators take part in the process of decision making independently. The operator of each electric power system controls its own system and does not possess the data on the state of neighboring power systems. In this situation, to calculate ATC of the cutsets the operator of each system establishes, what amount of additional power should be transmitted and what state variables are suggested to be changed, i.e. the values of limits of a potential change in the state variables and a

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value of the desired flow in the cutset. For the actions of operators not to contradict one another it is necessary to integrate them into a single procedure, according to which the cutsets will be loaded. The single procedure is developed using the TTC estimation method and artificial neural networks.

One of the ways to harmonize the actions of commercial operators that are aimed at additional loading of the controlled cutsets is the decentralized calculation of TTC and ATC.

At present the methods of decentralized TTC calculation are being devised [21]. The key barrier for decentralized TTC calculation is the necessity of considering the correlations between the electric power system areas. Each power transmission should be analyzed from the standpoint of the entire system.

The suggested methods for TTC calculation in the decentralized system can be divided into two categories. The first category introduces a two-level structure, and a megasystem of control of all control areas is constructed. The megasystem possesses all information on the system and is responsible for all calculations on the basis of this information. The two-level system protects private information of each control area, as far as the areas do not exchange this information. However, in this case construction of communication and computer infrastructures requires high investments. The second category of the methods is applied to create multi-level areas for TTC calculation. In these methods the use can be made of the algorithm of TTC calculation in the centralized control. The problem of TTC calculation in the multi-level areas is formulated as system decomposition into several subsystems representing an area level.

The paper presents the technique, which can be referred to the first category of TTC calculation methods. The control center to be created receives all the data from all systems, the state estimation and TTC estimation are performed and then the single procedure of loading the controlled cutsets is developed.

Section 2 of the paper presents the devised method for TTC estimation. Section 3 describes the technique of generating a trade-off solution on calculation of TTC and control actions aimed at ATC application in several cutsets simultaneously. Section 4 presents the results of calculations made for a real scheme. At the end of the paper the conclusions are drawn based on the research results.

II. TTC ESTIMATION

Solution to the TTC estimation problem is based on the idea that application of the weighted least squares method of the sums of TTC estimation residuals allows the desired solution to be obtained from any point with the required accuracy by selecting the weighting coefficients. For TTC calculation the criteria of the desired state are determined by each concerned subject (for example, commercial operator) in accordance with the own interests, which leads to formation of contradictory conditions. The interests of all subjects are coordinated by satisfying the constraints of each subject. Satisfaction of the constraints for TTC estimation is guaranteed by the corresponding values of the weighting coefficients of TTC pseudomeasurements.

The initial information for input data generation that is used to calculate the estimates of measurements and TTC (parameters of the resultant load flow solution) is the on-line and calculated information. The on-line information represents the data obtained from the SCADA system [24] and WAMS [25]:

$$\bar{y} = (U_i, P_i, Q_i, P_{ij}, Q_{ij}, \delta_i) \ , \qquad (1)$$

where U_i – magnitudes of nodal voltages; P_i , Q_i – injection of active and reactive powers at the nodes; P_{ij} ,Q_{ij} – power flows in transformers and lines, δ_i – voltage phases at the nodes of the scheme, in which PMUs are placed.

The calculated information is the TTC pseudomesurements (TTC PM) $P_{lk}^{TTC\ \ PM}$ of the controlled cutsets and their weighting coefficients.

The value of TTC pseudomeasurements is independent of the system schemes and states and is the constant calculated information that is generated in advance and stored in the database. For calculation of TTC pseudomeasurements each controlled line is represented by the simplest electric power system. The TTC pseudomeasurement for short lines is the total transfer capability of the line without violation of thermal stability. The TTC pseudomeasurement for long lines is the total transfer capability of the line without violation of steady-state stability.

The weighting coefficients of TTC pseudomeasurements can change with variation of the power system state and hence, are determined as the variable calculated information. Their values are calculated in advance by the enumeration method in terms of the system constraints and observance of the optimality criterion in selecting the weighting coefficients [26]:

$$\varphi_k = \sum_1^{kol} (P_{lk}^{TTC\ \ PM} - P_{lk}^{TTC}(x))^2 \to \min \ , \qquad (2)$$

where kol – number of controlled lines; P_{lk}^{TTC} – estimates of flows in the controlled lines.

The vector of measurements, which is applied to TTC estimation, looks as follows:

$$\bar{y}_{\text{RES}} = (\bar{y}^{\text{n}}, \bar{y}^{a}, P_{lk}^{TTC\ \ PM}) = (\bar{y},\ P_{lk}^{TTC\ \ PM}) \ , \qquad (3)$$

where $\bar{y}^{n}$ – measurements of nonadjustable (uncontrolled) state variables. The values of these variables in the calculation process remain within the accuracy of measurements; $\bar{y}^{a}$ – measurements of adjustable (controlled) state variables. The values of these variables can vary within the specified control limits [26].

The problem of TTC calculation is to search for admissible values that are most close to the specified inadmissible value $P_{lk}^{TTC\ PM}$, and is reduced to minimization of the objective function of the weighted least squares:

$$J(x)=(\bar{y}-y(x))^T R_y^{-1}(\bar{y}-y(x))+ \left(P_{lk}^{TTC\ PM}-P_{lk}^{TTC}(x)\right)^T R_p^{-1}\left(P_{lk}^{TTC\ PM}-P_{lk}^{TTC}(x)\right), \quad (4)$$

where R^{-1} – weighting coefficients of measurements, R_P^{-1} – weighting coefficients of $P_{lk}^{TTC\ PM}$.

The estimates of the resultant state are determined by minimization of criterion (4) and the system of nonlinear equations is solved by the iterative method

$$H^T R_{RES}^{-1}\left[\bar{y}_{RES}-y_{RES}(x)\right]=0, \quad (5)$$

where $R_{RES}^{-1}=\begin{bmatrix} R_y^{-1} & 0 \\ 0 & R_p^{-1} \end{bmatrix}$.

At each iteration the system is linearized at the solution point and the normal system of equations is solved. In the system the vector of corrections is calculated by the formula

$$\Delta x^l=\left[H^{T(l)} R_{RES}^{-1} H^l\right]^{-1} H^{T(l)} R_{RES}^{-1}\left[\bar{y}_{RES}-y_{RES}(x^l)\right] \quad (6)$$

where H^l – Jacobian matrix calculated at the l–th iteration.

The state vector is calculated by the formula

$$x^{l+1}=x^l+\Delta x^l. \quad (7)$$

The system of equations (5) is solved, until the condition

$$\Delta x^l<\xi_x \quad (8)$$

is observed. The state vector is used to calculate all state variables.

III. TECHNIQUE OF ATC APPLICATION

The proposed technique suggests a preparatory stage, in which the universal techniques are transformed into a technique for solving the problems in concrete electric power systems. In this stage we identify a range of problems to be solved, develop scenarios and find weighting coefficients for TTC pseudomeasurements that correspond to a set scenario, current state and imposed constraints. The weighting coefficients of TTC pseudomeasurements are stored in the database.

Figure 1 illustrates a scheme of on-line control of loading the cutsets. Each EPS is represented by three blocks: data capture, creation of a single procedure for generation of instructions on additional line loading and line loading.

Capture of data on state variables of EPS is performed by the SCADA system and WAMS. The measurement vector $\bar{y}_i$ is created in each system i from the measurements. The vector is transferred to the control center.

In the block of “formation of a *single procedure*” the document is created, in which:

- the control lines are indicated;
- the values of $P_{lk}^{TTC\ PM}$ in the indicated lines are specified;
- the regulated state variables are enumerated and the ranges of their changes are determined;
- the prepared information is transmitted to the control center.

Generation of instructions. Parameters of the resultant load flow solution and data on the control actions performed to obtain this solution are sent to each system of the interconnected EPS. The case, where the operators of all EPS agree with the TTC calculation results means a trade-off solution is achieved.

The functions of the control center are:

1. To set the operational constraints of the interconnected power system y^{con}.
2. To compile on-line information

$$\bar{y}=(\bar{y}_1,\bar{y}_2,.\bar{y}_l\,..\bar{y}_L), \quad (9)$$

where L – number of the concerned EPSs. Vector $\bar{y}$ is transferred to the state estimator and to the TTC estimator.

3. To perform the state estimation procedure.
4. To compile the calculated information

$$P_{lk}^{TTC\ PM}=(P_1^{TTC\ PM},P_2^{TTC\ PM},.P_j^{TTC\ PM}\,..P_J^{TTC\ PM}), \quad (10)$$

where $P_j^{TTC\ PM}$ – pseudomeasurements of TTC of the controlled lines. J – number of the controlled lines.

5. To form the input vector for ANN1 based on constraints y^{con} and to form the input vector for ANN2 based on the on-line information $\bar{y}=(\bar{y}_1,\bar{y}_2,..\bar{y}_L)$. The trained ANN selects R_P^{-1} (4) from the database. The process of ANN learning is not considered in this paper.
6. To construct the resultant vector of initial data

$$\bar{y}_{\mathrm{RES}}=(\bar{y}\ ,P_{lk}^{TTC\ PM}). \quad (11)$$

7. To calculate the resultant load flow solution of the interconnected EPS based on vector $\bar{\mathrm{y}}_{\mathrm{RES}}$ with the TTC estimation method. The vector of estimates of the resultant load flow solution has the form:

$$\hat{y}_{\mathrm{RES}}=(\hat{y}\ ,\hat{P}_{lk}^{TTC}). \quad (12)$$

8. To calculate the controlled actions based on the results of TTC estimation and state estimation.
9. To communicate the information about each EPS to the block of generation of instructions for the each system.

IV. APPLICATION OF THE TECHNIQUE BY THE EXAMPLE OF A REAL CALCULATED SCHEME

A. General characteristic of the scheme and description of scenarios

The calculated scheme, shown in fig.2, includes 17 nodes, 21 (500 kV) transmission lines, and two controlled cutsets. Controlled cutset 1 is one-circuit line 1-5 and two-circuit line 2-3, controlled cutset 2 is represented by lines 11-15 and 12-15. The TTC values of two controlled cutsets are calculated on the basis of three scenarios. Scenario 1: TTC and ATC are calculated in cutset 1; Scenario 2: TTC and ATC are calculated in cutset 2; Scenario 3: TTC and ATC are calculated in cutsets 1 and 2 at their simultaneous loading.

B. TTC calculation of cutset 1 (Scenario 1)

This problem is solved by the following Scenario: calculation of TTC estimates at transmission of additional power from node 2 to node 5.

The value of the surge-impedance loading is used as a value of the TTC PMs of the lines in the controlled cutset [28].

$$P_{1-5}^{TTC\ \ PM}=900 \quad , \tag{13}$$

$$P_{2-3}^{TTC\ \ PM}=1800 \quad . \tag{14}$$

The constraints applied in the calculation of weighting coefficients of the TTC PMs are represented by the following inequalities:

$$\overline{P}_2 \le \hat{P}_2 \le 3431 \ , \tag{15}$$

$$0 \le \hat{Q}_2 \le 501 \quad , \tag{16}$$

$$0 \ \le \hat{Q}_4 \le 342 \quad , \tag{17}$$

$$490 \le \hat{U}_7 \le 524 \ , \tag{18}$$

$$\overline{y}_i - 3\sigma \le \overline{y}_i \le \overline{y}_i + 3\sigma \quad , \tag{19}$$

where $\overline{P}_2$, $\hat{P}_2$ – measurement and estimate of active power generated at node 2, $\hat{Q}_2$, $\hat{Q}_4$ – estimates of reactive power generated at nodes 2 and 4, $\hat{U}_7$ – estimate of voltage magnitude at node 7, σ – standard deviation.

Expression (19) means that at the nodes with nonadjustable parameters the values of measurements should remain within a range of $\pm 3\sigma$.

C. TTC calculation of cutset 2 (Scenario 2)

The stated problem is solved by the following scenario: transmission of additional power from node 15 to nodes 11 and 12.

The value of the surge-impedance loading is used as a value of the TTC PMs of the lines in the controlled cutset [28]

$$P_{11-15}^{TTC\ \ PM}=900 \quad , \tag{20}$$

$$P_{12-15}^{TTC\ \ PM}=900 \quad . \tag{21}$$

The constraints applied to the calculation of weighting coefficients of the TTC PMs are represented by the following inequalities

$$\overline{P}_{15} \le \hat{P}_{15} \le 1430 \quad , \tag{22}$$

$$0 \le \hat{Q}_{11} \le 50 \ , \tag{23}$$

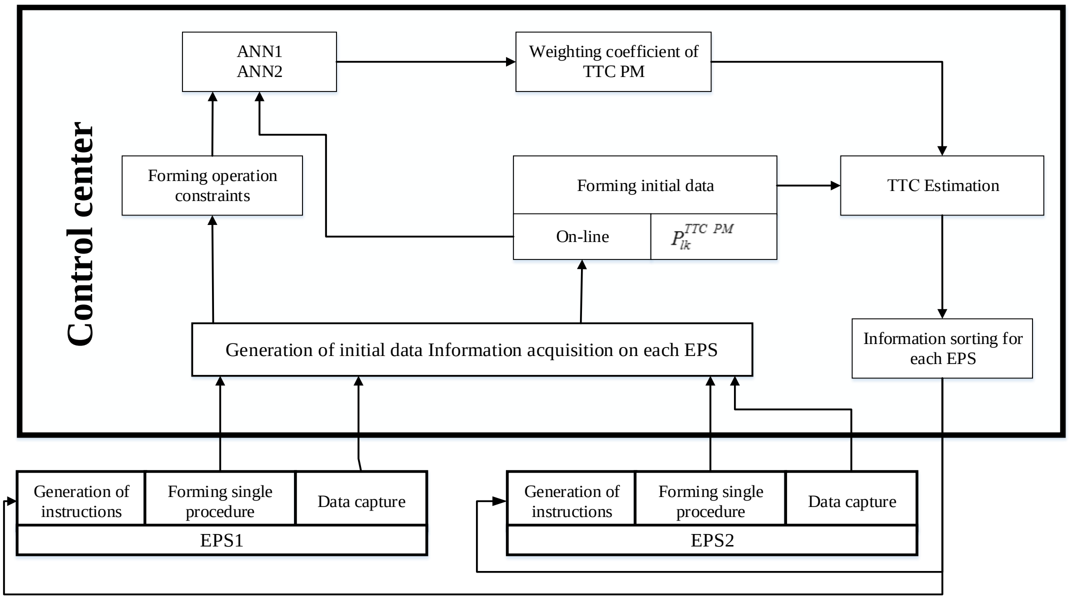

Figure 1. A scheme of online control of loading the lines on the basis of the trade-off approach.

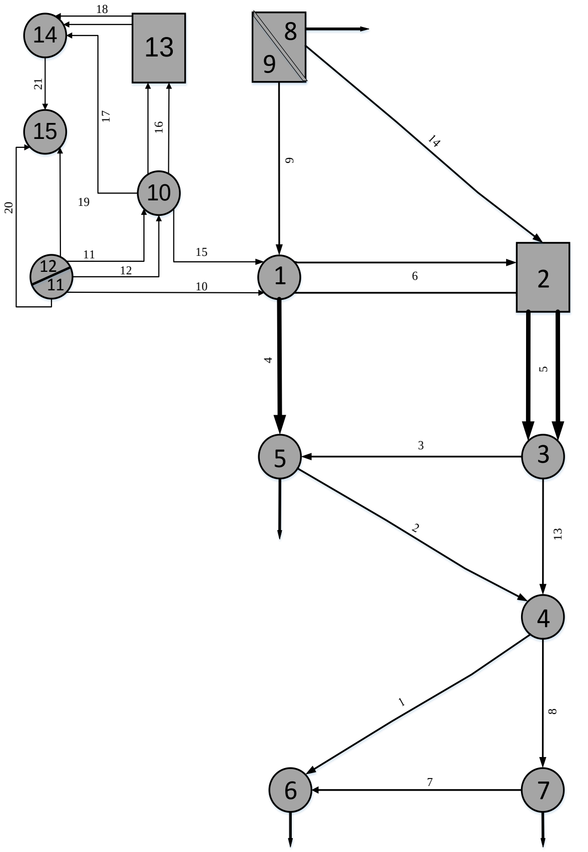

Figure 2. A scheme of a real electric power system.

$$0 \le \hat{Q}_{12} \le 50 \qquad (24)$$

and expression (19),

where $\bar{P}_{15}$, $\hat{P}_{15}$ – measurement and estimate of active power generated at node 15, $\hat{Q}_{11}$, $\hat{Q}_{12}$ – estimates of reactive power generated at nodes 11 and 12.

D. TTC calculation of cutsets 1 and 2 simultaneously (Scenario 3)

The problem is solved by the following scenario: transmission of additional power from node 15 to nodes 11 and 12, and from node 2 to node 5. The constraints applied to the calculation of weighting coefficients of the TTC pseudomeasurements $P_{1-5}^{TTC\ \ PM}$, $P_{2-3}^{TTC\ \ PM}$, $P_{11-15}^{TTC\ \ PM}$ are represented by inequalities (15)– (19), (22)–(24). The trade-off solution is guaranteed by satisfaction of these constraints at loading of two cutsets.

E. Calculation results

Figures 3, 5, 7 show the values of difference between the parameters of the current and resultant load flow solutions that are obtained at TTC calculation by Scenarios 1, 2 and 3, respectively. Figures 4, 6, 8 present the active power flows of the controlled lines for Scenarios 1, 2 and 3, respectively.

Figures 3, 5, 7 show that all commitments to consumers are met, as far as the state variables changed only at the controlled nodes. In Scenario 1 (Fig.3) active power changed at nodes 2 and 5 (curve P), reactive power changed at node 4 (curve Q), voltages at all nodes remained within the prescribed limits (curve U). In Scenario 2 (Fig.5) active power changed at nodes 11, 12 and 15 (curve P), reactive power changed at nodes 11, 12 (curve Q), voltages at all nodes remained within the prescribed limits (curve U). In Scenario 3 (Fig.7) active power changed at nodes 2, 5, 11, 12 and 15 (curve P), reactive power changed at nodes 4, 11, 12 (curve Q), voltages at all nodes remained within the prescribed limits (curve U).

Analysis of the graphs in Figs. 3, 4 for Scenario1 (Figs. 5, 6 for Scenario 2) allows the conclusion that the maximum power that can be transmitted in controlled cutsets 1 and 2 under the specified conditions of the EPS operation is equal to 1736,6 MW and 847,2 MW, respectively. ATC of cutset 1 is 107 MW, ATC of cutset 2 is 353 MW. Additional power equal to 104 MW (422 MW) can be transmitted owing to the following control actions: increase of reactive power generation at node 4 by 25 MVAr (at nodes 11 and 12 by 36 and 39 MVAr, respectively).

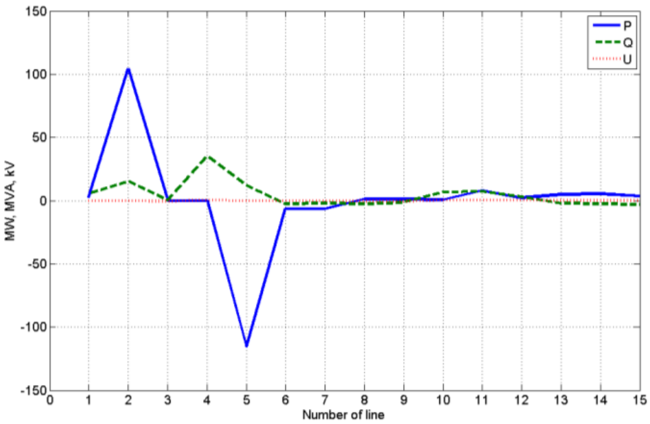

Figure 3. Deviations in active power, reactive power and voltage (Scenario1).

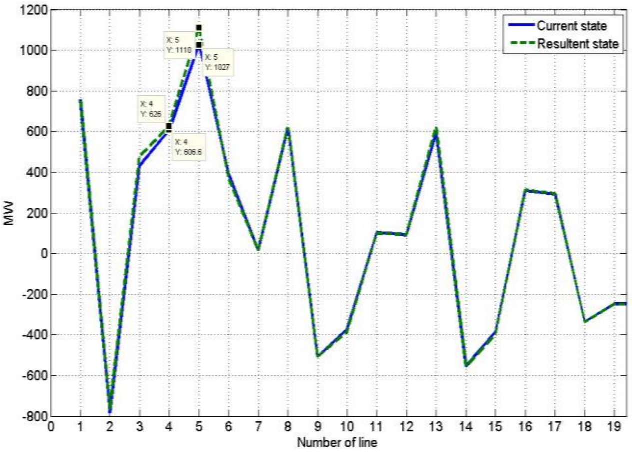

Figure 4. Active power flow in actual and resultant load flow solution (Scenario 1).

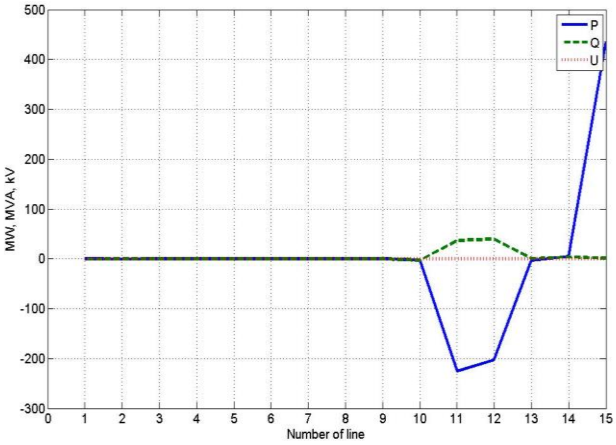

Figure 5. Deviations in active power, reactive power, voltage (Scenario2).

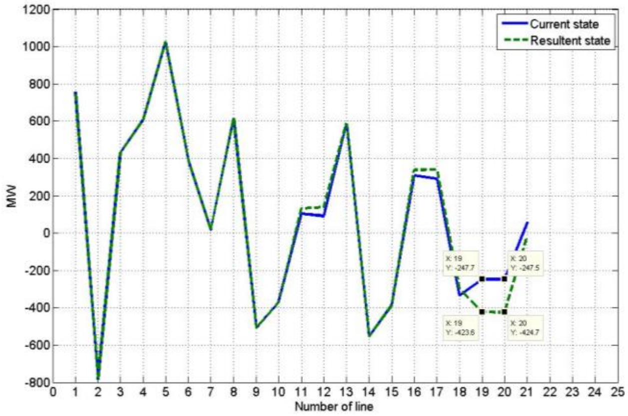

Figure 6. Deviations of active power flow in current load flow solutions (Scenario 2).

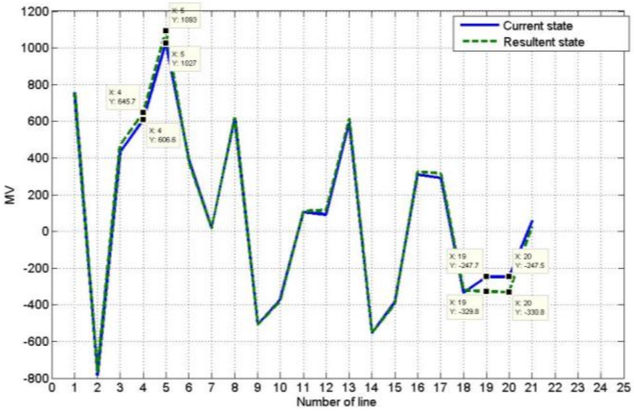

Figure 7. Deviations in active power, reactive power, voltage (Scenario 3).

Table 1 compiles the calculation results obtained for three Scenarios. Number of the cutest is given in the first line, the TTC value in the controlled cutset for each Scenario – in the second line. The ATC values of the controlled cutsets are written in the third line. The values of additional active power generation are presented in the fourth line. Controlled actions are showed in the fifth line.

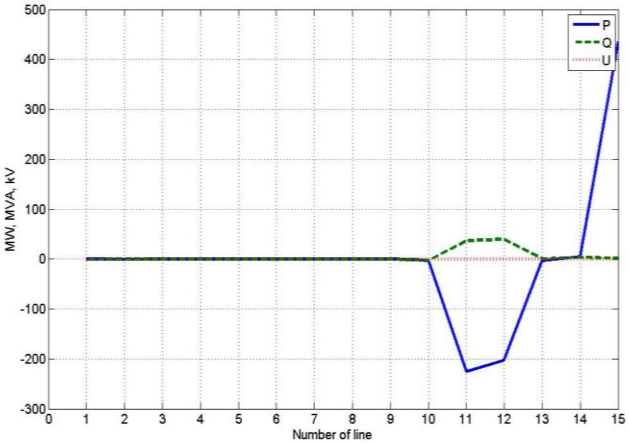

Figure 8. Active power flow in current and resultant states (Scenario 3).

Table 1. Calculation results for three Scenarios

Number of cutset	**1**	**2**	**1**	**2**
			simultaneously	
Flow current (MW)	1633	494	1633	494
resultant	1736	847	1709	660
ATC (MW)	107	353	76	165
Additional generation (MW)	$P_2 = 104$	$P_{15} = 435$	$P_2 = 82$	$P_{15} = 202$
Control actions (MVAr)	$Q_4 = 25$	$Q_{11} = 36$ $Q_{12} = 39$	$Q_2 = 20$ $Q_{11} = 21$	$Q_4 = 23$ $Q_{12} = 22$

The last two columns present the results of the tradeoff solution. Analysis of the results in Table 1 shows that if the additional active power is transmitted simultaneously in the independent cutsets, the transmitted power values in each cutest prove to be lower than the power that can be transmitted in the same cutsets, but at different time intervals.

V. CONCLUSIONS

The paper presents a trade-off approach for calculation of the total transfer capability in two cutsets simultaneously. The TTC is calculated in a decentralized manner. The approach supposes that EPSs do not share their data among themselves. The approach supposes that EPSs do not share their data among themselves. These EPSs want to cooperate via a control center to calculate total transfer capability and available transfer capability. State estimation, estimation of total transfer capability and calculation of control actions aimed at the achievement of total transfer capability in the controlled cutsets are performed in the control center. The tradeoff solution is considered to be reached, if operators of all electric power systems agree with the control actions, and the total transfer capability values to be obtained, when these control actions are implemented.

The developed method was tested by the determination of total transfer capability and available transfer capability in two cutsets of some electric power system. The calculations were made at loading of each considered cutset alternately and at simultaneous loading of the considered cutsets. Analysis of the results confirms that:

- the TTC and ATC values depend on the current conditions of electric power system operation. With the additional power flow transmitted simultaneously in cutsets 1 and 2, the value of ATC in cutset 1 is less by 27 MW and in cutset 2 - by 187 MW than the value of ATC in the case of power transmission over cutsets 1 and 2 at different time intervals;
- the interests of all electric power systems participating in TTC and ATC calculation have been taken into consideration using the trade-off approach. The values of active and reactive generation are only changed in controlled state variables.

REFERENCES

[1] K. Audomvongseree and A. Yokoyama, “Consideration of an appropriate TTC by probabilistic approach,” *IEEE Trans. on Power Systems*, vol. 19, no. 1, February, 2004.

[2] Li Weixing, Peng Wang, Zhizhong Guo, “Determination of optimal total transfer capability using a probabilistic approach,” *IEEE Trans. on Power Systems*, vol.21, no. 2, May, 2006.

[3] *Glossary of Terms prepared by the Glossary of Terms task force North American Electric Reliability Council* (NERC). August, 1996.

[4] A.M. Kontorovich, A.V. Kryukov, “The use of equations of limiting conditions in the problems of electric power system control,” *Izv. AS USSR. Energy and Transport*, no3, pp.25–33, 1987. (in Russian)

[5] A.V. Pazderin, P.V. Chusovitin, G.S. Shabalin, S.V. Yuferev, “Determining the control actions to ensure the static stability in the emergency control problem based on Newton’s method in optimization,” *5th International Scientific and Technical Conference “Current trends in the development of relay protection and automated systems in energy systems”*, Sochi, pp. 2–9, June 1–5, 2015.

[6] B.I. Ayuev, V.V. Davydov, P.M. Erokhin, “Optimization models of the nearest limiting conditions of electric power systems,” *Electrichestvo*, no. 11, pp.2–9, 2010. (in Russian)

[7] Priti Kachore, M. V. Palandurkar, “TTC and CBM Calculation of IEEE–30 Bus System,” *Second International Conference on Emerging Trends in Engineering and Technology (ICETET)*, pp. 539–542, 2009.

[8] Hamid Falaghi, Maryam Ramezani, Chanan Singh, Mahmood-Reza Haghifam, “Probabilistic Assessment of TTC in Power Systems Including Wind Power Generation,” *IEEE Systems journal*, vol. 6, no. 1, pp. 181–190, March, 2012.

[9] M. R. Aghaebrahimi, R. Kazemi, Golkhandan, and S. Ahmadnia, “Probabilistic Calculation of Total Transfer Capability (TTC) for Power Systems with Wind Farms using Evolutionary Algorithms,” *9th International Conference on Power Electronics–ECCE Asia 63 Convention Center*, Seoul, Korea, pp. 2135-2140, 1 – 5, June, 2015.

[10] Yunfei Chu, Zhinong Wei, Guoqiang Sun, Li Yichi, “Fast calculation of available transfer capability incorporating uncertainty of wind generation,” *5th International Conference on Electric Utility Deregulation and Restructuring and Power Technologies (DRPT)*, pp. 2486–2490, 2015.

[11] A.S. Alexandrov, D.M. Maximenko, A.F. Mikhailenko, V.G. Neuimin, “Development of a system for monitoring of stability margins and dynamic stability control to consider the effect of emergency control,” *Proc. of STC UPS*, no.1 (76), pp. 64–72, 2017. (in Russian)

[12] R. Rajathy, R. Gnanadass , V. Vincy , Shaliney Esther Ambroise, Harish Kumar, “ Total Transfer Capability Enhancement using Differential Evolution,” *Control, Automation, Communication and Energy Conservation (INCACEC)*, pp. 1–8, 2009.

[13] M. Yilmaz, B. Bilir, “Determination of Power Transfer Capability by Incremental Changes,” *IEEE Electrical Power & Energy Conferenc (EPEC). Canada*, 21–23 August, 2013.

[14] Piyush Warhad Pande, A. K. Sinha, “ Total Transfer Capability Calculation Considering Variation of Ambient Temperature - A Case Study,” *IEEE Power, Communication and Information Technology Conference (PCITC)*, pp.727–731, 2015.

[15] A.N. AL-Masri, M. Z. A. A. Kadir, H. Hizam, N. Mariun, S. Yusof, “Control Action based on Steady-State Security Assessment using an Artificial Neural Network,” *IEEE International Conference on Power and Energy (PECon2010),* Kuala Lumpur, Malaysia, pp. 706-711, Nov 29 – Dec 1, 2010.

[16] H. Buch, K.K. Dudani, D.P. Pipalava, “ Prediction of Total Transfer Capability using ANN in Restructured Power System,” *5th Nirma University International Conference on Engineering (NUiCONE)* , pp. 1–5, 2015.

[17] N.D. Ghawghawe, K.L. Thakre, “Application of power sensitivity analysis and PTDF for determination of ATC,” *Conference paper: Power Electronics, Drives and Energy System*, January. 2007.

[18] Kowshik Mushfiq-Ur-Rahman, Md. Saiduzzaman, Md. Naieem Mahmood, Md. Rokunuzzaman Khan. “Calculation of Available Transfer Capability (ATC) of Bangladesh Power System Network,” *Department of Electrical and Electronic Engineering Ahsanullah University of Science and Technology*. Bangladesh, IEEE ISGT Asia, pp. 1–5, 2013.

[19] Xiaochen Zhang, Santiago Grijalva, “Decentralized Total Transfer Capability Evaluation Using Domain Decomposition Methods,” *IEEE Transactions on Power Systems*, vol. 31, no5, pp. 3349–3357, 2016.

[20] Xiaochen Zhang, James Jamal Thomas, Santiago Grijalva, "Fast Evaluation of Probabilistic Total Transfer Capability Considering Multiple Wind Farms," *IEEE/PES Transmission and Distribution Conference and Exposition (T&D),* 2016.

[21] Liang Min, and Ali Abur, "Total Transfer Capability Computation for Multi-Area Power Systems," *IEEE Transactions on power systems,* vol. 21, no 3, pp.1141–1147, August 2006.

[22] Chengshan Wang, Xinggang Wang, and Pei Zhang, "Fast Calculation of Probabilistic TTC with Static Voltage Stability Constraint," *Power Engineering Society General Meeting, IEEE,* 2007.

[23] L.S. Kosobov, "Assessment of technical and economic efficiency of power system operation control to prevent instability," *Polzunov Almanac*, no.2, pp. 56–59, 2009. (in Russian)

[24] [Online]. Available: https://en.wikipedia.org/wiki/Energy_management_system

[25] A.G. Phadke, "Synchronized Phasor Measurements. A Historical Overview," *IEEE/PES Transmission and Distribution Conference*, vol. 1, pp. 476-479, 2002.

[26] A.M. Glazunova, E.C. Aksaeva, "Available transfer capability determination on the basis of a trade-off approach," *Proceedings of the International Conference PowerTech*, Manchester, UK, 18–22 June, 2017.

[27] A.M.Glazunova, I.N.Kolosok, E.S.Korkina, "Monitoring of EPS Operation by the State Estimation Methods", *Proc. of the International Conference "Innovative Smart Grid Technologies " (ISGT Europe-2011),* Manchester, UK, 5–7 December, 2011.

[28] *Electric Power Systems. Definition of preliminary technical solutions for power output.* JSC "UPS of Russia", 2007. [Online]. Available: http://so-ups.ru/fileadmin/files/laws/standards/NRG_system.pdf (in Russian)

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