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STATIC AND DYNAMIC SIMULATIUON MODELS FOR REACTIVE POWER FLOW CONTROL IN POWER SYSTEM BY MEANS OF STATCOM DEVICE

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Abstract- Information about some features of damping of oscillations of active and reactive powers when using F-STATCOM device in networks of power system with industrial load (having cooling loads in a large measure) and possible areas of its application is presented in the paper. Requirements for traditional thyristor control system of F-STATCOM device, their shortcomings, alternative control algorithm proposed based on fuzzy logic theory and results of calculations for simulation modeling are given. In simulation model the STATCOM device action was considered in statics and dynamics.

Keywords: FACTS Device, STATCOM, Active and Reactive Power Flow Control, Power Balance, Voltage Transducer, Fuzzy Logic, Membership Function, Phase Inverter Transformer.

1. INTRODUCTION

The technologies, existing in the field of electric power transmission, develop in the direction of their control, increase of dynamic stability and reliability. At the same time, high quality of electrical energy in the power supply must be ensured [1, 2]. One of the main methods to achieve this goal is to use the (FACTS) system of controlled (active) AC power line.

Currently, FACTS facilities, being one of the most promising technologies of electrical networks, form a comprehensive technical and information system for automatic control of power line parameters [3-6]. FACTS facilities convert the electrical network from a passive device into an active member of the control of electric energy transportation, its operating mode, and is applied to adjust the power factor, minimize losses, etc.

FACTS facilities of the first generation provide voltage regulation and reactive power compensation within the required limits in electrical networks. These cover a static reactive power compensator (SC), SCR's controlled reactor, series stationary SCR's controlled capacitor, phase-shifting transformer, etc. [7-12].

The newest second generation of FACTS includes the facilities that provide regulation of mode parameters based on fully controlled power electronics (insulated-gate bipolar transistors IGBT, integrated driver gate-controlled thyristor IGCT, etc.). FACTS facilities of this type regulate both the voltage vector phase and the vector value and have a new quality of regulation. Such facilities include synchronous static compensator (STATCOM), regulator of cumulative power flows, an asynchronized synchronous compensator, including a flywheel [13], asynchronized synchronous electromechanical frequency converter, controlled shunt reactors [14].

One of the classes of such FACTS facilities is the STATCOM device with a high-speed multifunctional reactive power compensator. STATCOM is a static controlled device, which is performed according to the voltage transducer scheme and is connected parallel to the electrical circuit.

As a reactive power source, the STATCOM provides as follows [15-17]:

a) increase of the capacity of electrical networks with different voltage classes;

b) voltage retention at substations of network with long-time and heavy load in normal, emergency and post-emergency conditions;

c) excess switching voltage restriction;

d) voltage balancing, etc.

The results of improvement of the STATCOM device control system based on fuzzy logic and the results of calculations are presented in the paper.

2. CHARACTERISTICS OF ACTIVE AND REACTIVE POWER CONTROL IN POWER SYSTEM

Recently, system accidents occur in the power system due to the connection of a large number of air conditioners to the electrical network due to a sharp rise of air temperature [18]. The situation is further complicated by the presence of numerous low-power electric motors as part of the power system load (electric motors of air conditioners, fans and household appliances). Currently, the share of these loads in the power system is quite high, and their mechanical temporal stability is much lower than the mechanical temporal stability of powerful electric generators. Just due to the mentioned reasons, the winter and summer maximums of the system are almost equal, even sometimes the increase of summer maximum is observed. This can be seen from the annual load curve derived from the measurement data on the example of one area of the real power system (Figure 1).

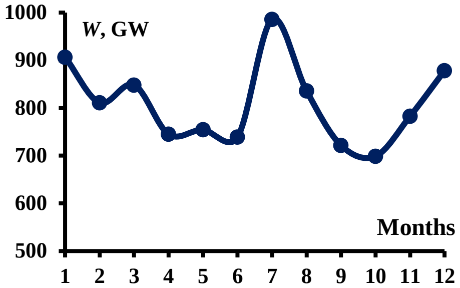

Figure 1. Annual load curve for power system area in 2018

Figure 1 shows the electricity demand in January-December was 878,1-907,7-878,1 GW, and in July - 985.8 GW. In other words, the summer maximum was higher than the winter maximum by 8.6%.

The power system stability and quality are determined by the balance of active and reactive powers. As a rule, for the construction of load consumption curve it is advisable to use power system load consumption curve [19]:

$$P_{ij}+\sum_i P_{CV,i}=\sum_k P_{G(ES),k}\pm\sum_m P_{Con,m}- \\ -\sum_k P_{OE,k}-\sum P_L \tag{1}$$

$$Q_{ij}+\sum_i Q_{CV,i}=\sum_k Q_{G(ES),k}\pm\sum_m Q_{Con,m}+\sum_l Q_{B,W,l}- \\ -\sum_k Q_{OE,k}-\sum Q_L \tag{2}$$

where, $P_{ij}+\sum_i P_{CV,i}$ and $Q_{ij}+\sum_i Q_{CV,i}$ are active and reactive required loads, including air conditioners, fans and other household appliances; $\sum_k P_{G(ES),k}$ and are active and reactive generation powers produced at power plants; $\sum_m P_{Con,m}$ and $\sum_m Q_{Con,m}$ are active and reactive powers transmitted on the network; $\sum_k P_{OE,k}$ and $\sum_k Q_{OE,k}$ are special consumption active and reactive powers of power plants; $\sum P_L$ and $\sum Q_L$ are active and reactive power losses respectively in electric networks; and $\sum_l Q_{B,W,l}$ charging power generated by PTL.

As it is known, voltage stabilization in the power system is carried out by regulation of the reactive power values of generators, electric machines and static reactive power compensators, disconnection-connection of reactive loads (reactors). Frequency stabilization in the power system is achieved by regulation of active powers of power plants. In the modern period, the reactive power regulation in power systems is carried out at a speed of up to 20-50% of its nominal value per second, even at an even greater speed (for terminal static compensators) [19]. To ensure high-quality voltage stabilization in the power system, this speed of its regulation in most cases is sufficient.

Active power regulation of power plants of the power system is possible only at an even lower speed. So, the active power regulation of thermal power plants is usually carried out at a speed not exceeding 15% of the rated power per minute. For hydroelectric power plants it is allowed to change the active power at a speed of up to 5-10% of the nominal value per second. The active power change of diesel and gas turbine power plants is made at approximately the same speed. In the modern period, even faster active power oscillations can be compensated only by the energy of flywheel masses of rotating units of the system. The permissible level of this energy transmission is limited by the possible deterioration of the electrical energy quality in the system.

As it is known, to stabilize the voltage and frequency in the power system, the balance equations (1) and (2) must be provided at any time. In case of violation of this balance in the power system, as noted above, the use of controlled (flexible) AC power transmission system (FACTS-Flexible Alternative Current Transmission System) is considered promising. At the same time, it should be noted that due to various reasons, the change in the load curve of the power system is random, and under such conditions, the regime control requires the use of special mathematical tools. Daily load curves for one area of power system are presented in Figure 2 [20].

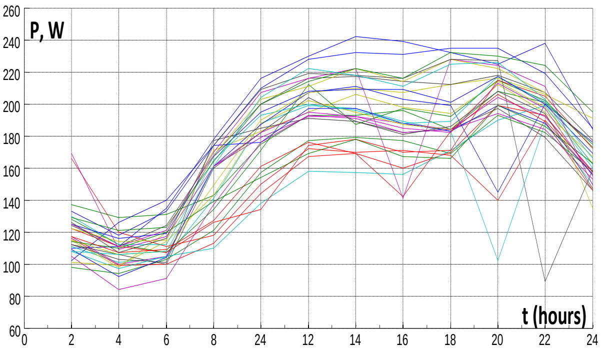

Figure 2. Daily load curve for one area of power system

As can be seen, the daily change of the load curve is uncertain and random. In such conditions, the lack of control over the power balance can lead to negative results, or rather to a violation of stability. One of the optimal methods to ensure stability is the introduction of different types of energy storage devices into the power system. As one of such storage devices is the use of pumped-storage plant. However, in most power systems, the introduction of this type of station is not possible due to the influence of various factors. In such power systems, as an important measure to maintain stability, it is advisable to use STATCOM, which is one of the fast-operating FACTS facilities that restore the power balance (1) and (2) in real time. Results of modeling of the influence of F-STATCOM device with fuzzy control algorithm to control the flows of active and reactive powers in the power system with a load consumption with significant cooling electric receivers of (30-40)% are given below.

3. REACTIVE POWER COMPENSATION BY STATIC SYNCHRONOUS REACTIVE POWER COMPENSATOR

The creation of gate-controlled thyristors and controlled bipolar transistors allows for creating fully controlled semiconductor converters - voltage inverters, and on their basis- STATCOM, which is a new generation of FACTS device. Structure chart and vector diagram of STATCOM are shown in the Figure 3.

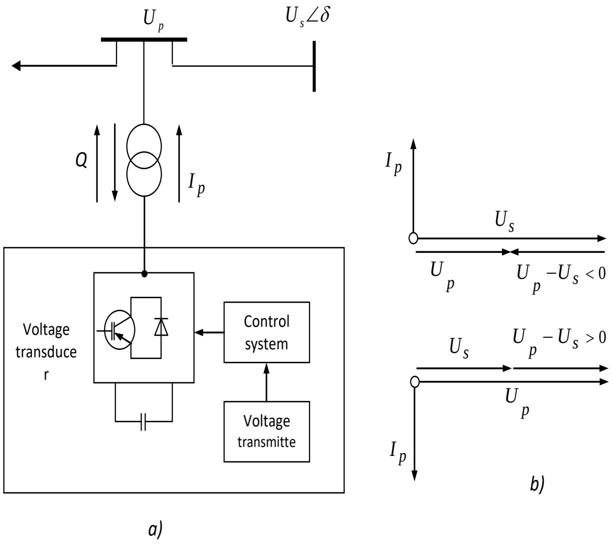

Figure 3. Structure chart (a) and vector diagram (b) of STATCOM

As can be seen from the vector diagram, during the reactive power consumption, the output voltage U_p of the converter, being less than the line voltage, is in the same phase with it. During generation it is in the same phase with the new voltage.

The active and reactive powers of the network are expressed as follows:

$$P = \frac{U_p U_s}{X}\sin\delta \tag{3}$$

$$Q = \frac{U_s^2}{X} - \frac{U_p U_s}{X}\cos\delta \tag{4}$$

where, X is inductive impedance of the system; and δ is angle between voltage vectors U_s and U_p.

The current-voltage characteristic of the STATCOM device is shown in Figure 4 [5]. The characteristic confirms the performance of compensator with excessive load in capacitive and inductive modes. The maximum current generated by the static compensator during strong disturbances in the capacitive mode is determined from the maximum current value that can be switched by the controlled valve inverter. With voltage reduction, the STATCOM will increase the dynamic stability limit, generating reactive power for account of excess load due to current.

As can be seen from the expressions (3) and (4), the STATCOM device control system can be synthesized based on $U_g = f(P, Q)$ relationship. However, depending on the P and Q schemes and the regime parameters, due to the fact that this relationship does not have an exact analytical expression, it is possible to use a control system based on the fuzzy logic theory. Block diagram of such control system is given in Figure 5. As can be seen, the control system is given based on fuzzy controller (FC).

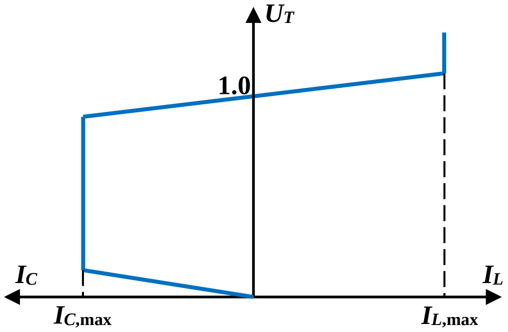

Figure 4. STATCOM voltage-current curve characteristic

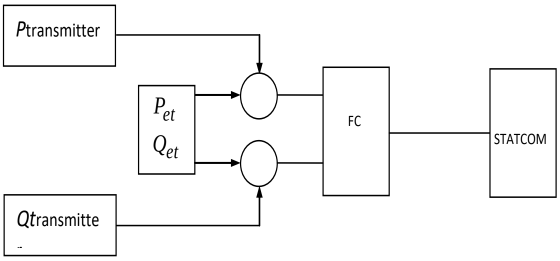

Figure 5. Block diagram of STATCOM fuzzy control

4. SIMULATION RESULTS

The model of the controller based on the fuzzy dependence adopted for the F-STATCOM control system is given in Figure 6.

Three-Phase Source simulates an electrical energy source, Three-Phase Pi Section Line-Line with distributed parameters, QF1 simulates a circuit breaker for disconnection and connection of STATCOM device, and QF"-QF5 simulates breakers that perform changes in the total load, which has a large proportion of cooling devices (air conditioner, fan, etc.), every 4 seconds.

Thus, the simulation model is created with a load change in 4 stages. The voltage step change curves at the end of the line are presented in Figure 7.

As can be seen from the comparative analysis of the curves obtained, along with a step load increase in the absence of the F-STATCOM action, the voltage will also decrease stepwise. At that the F-STATCOM device with fuzzy control system, having an effect, stabilizes the voltage significantly.

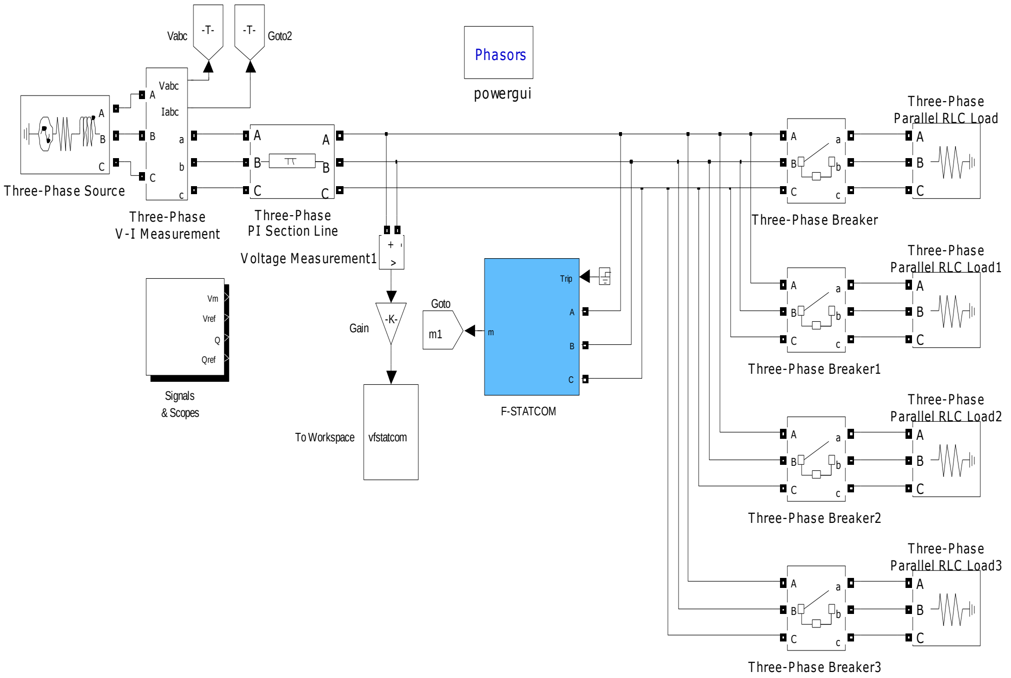

Figure 6. Simulation model of reactive power compensation by F-STATCOM device

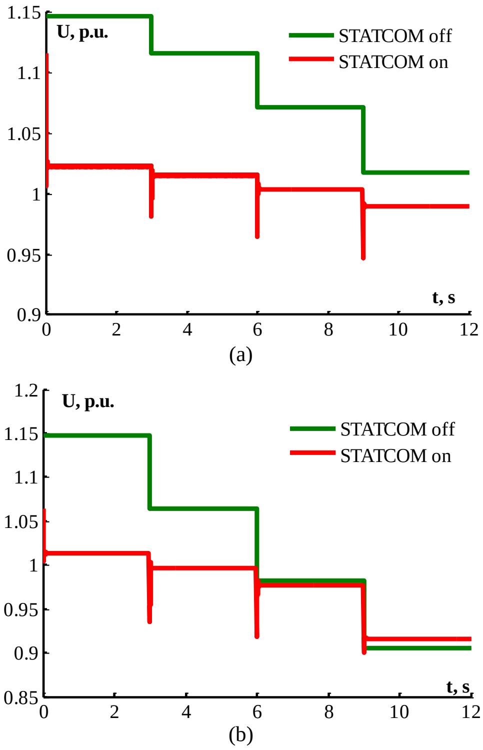

Figure 7. Voltage curves at the end of line in the cases of availability and absence of F-STATCOM device: (a) during only active power transmission from line; (b) during active and reactive power transmission from line

Transient process curves, formed in the case of F-STATCOM device action during active, active-reactive power flows, are represented in Figure 8(a) and Figure 8(b). As is obvious, the dynamic changes during short period are damping and the effective distribution of power flows and the required voltage level respectively are provided.

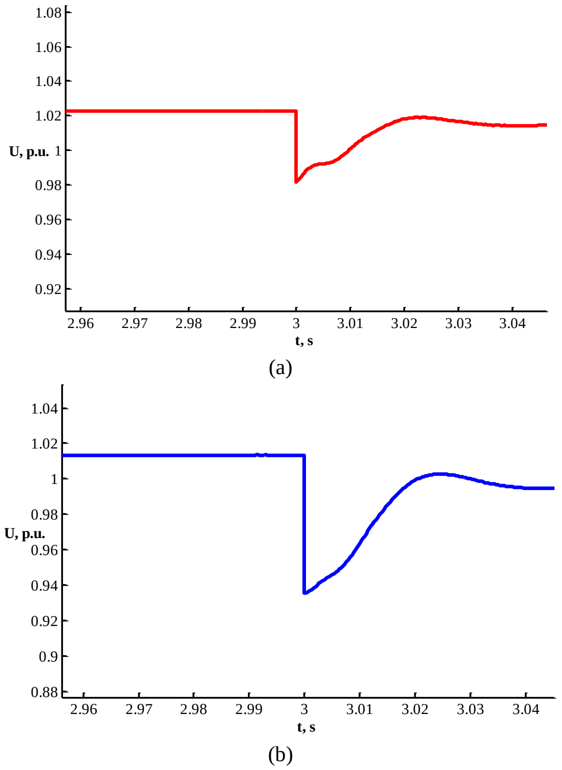

Figure 8. Transient process curves formed under the F-STATCOM device action: (a) during only active power transmission from line; (b) during active and reactive power transmission from line

5. CONCLUSIONS

In conditions of total load from a large number of coolers (air conditioner, fan, etc.) and electrical receivers with a small mechanical time characteristic as part of FACTS facilities for the compensation of fluctuations of active and reactive powers in the power system, taking into account the influence of various uncertain factors, they cannot fully meet modern requirements. Some algorithms in static modes have an effective action, however, in the conditions of sharp dynamic changes their action is not satisfactory.

The effectiveness of the use of static synchronous compensator (F-STATCOM) with control system on the basis of modern mathematical technologies (fuzzy logic) in order to compensate fluctuations of active and reactive powers to preserve the stability of the power system, in which a large proportion in the total load falls on coolers and other household loads, was considered. Stabilized voltage change diagrams, obtained under the influence of the F-STATCOM device based on simulation, prove its effectiveness.

Transient process curves, formed as a result of F-STATCOM device action in dynamic modes, show that in both cases under study during approximately one period the process and the voltage fluctuations are damping. This characteristic shows that F-STATCOM device, controlled based on fuzzy algorithm, has an effective action in transient modes too.

REFERENCES

[1] GOST 32144-2013, Electric Energy, "Electromagnetic Compatibility of Technical Means", Standards of Quality of Electric Energy in Power Supply Systems of General Purpose, M., Standard Inform, p.18, 2014.

[2] A.N. Norouzi, A.M. Sharaf, "Tow Control Schemes to Enhance Dynamic Performance of STATCOM and SSSC", IEEE Transactions on Power Delivery, Vol. 20, No. 1, pp. 435-442, 2005.

[3] N.N. Solonina, K.V. Suslov, Z.V. Solonina, "New Technologies of Reactive Power Compensation", Vestnik GTU, No. 5, Vol. 112, pp. 135-143, 2016.

[4] S. Musunuri, G. Dehnavi, "Comparison of STATCOM, SVC, TCSC, and SSSC Performance in Steady State Voltage Stability Improvement", North American Power Symposium (NAPS'10), Arlington, VA, USA, September 2010.

[5] M.J. Hossain, H.R. Rota, "Improved Low-Voltage-Ride-thorough Capability of Fixed Speed Wind Turbines Using Decentralized Control of STATCOM with Energy Storage System", IET Generation, Transmission & Distribution, Vol. 6, No. 8, pp. 719-730, 2012.

[6] C. Enang, B.K. Johnson, "Enhanced Modular Multilevel Converter Based STATCOM with Hybrid Energy Storage", IEEE Power & Energy Society General Meeting (PESGM), Atlanta, GA, USA, pp. 1-5, 2019.

[7] S. Bindeshwar, K. Verma, et al., "Introduction to FACTS Controllers - A Critical Review", International Journal of Reviews in Comput., Vol. 8, pp. 17-34, 2011.

[8] J. Sohoni, S.K. Joshi, "A Survey on Transient Stability Studies for Electrical Power Systems", Clemson University Power Systems Conference (PSC), Charleston, SC, USA, pp. 1-6, 4-7 Sept. 2018.

[9] L.P. Kalinin, D.A. Zaitsev, M.S. Tirsu, I.V. Qolub, "The Opportunities for Efficiency Increase of Phase-Shifting Transformers in Power Transmission Operational Modes", IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe), Bucharest, Romania, pp. 1-5, 29 Sept.-2 Oct. 2019

[10] J.T. Morrell, J.G. Eggebraaten, "Applications for Phase-Shifting Transformers in Rural Power Systems", IEEE Rural Electric Power Conference (REPC), Bloomington, MN, USA, pp. 70-74, 28 April-1 May 2019.

[11] A.C. Brilinsky, B.A. Kritsky, L.C. Smirnova, "Peculiarities of the Use of Phase Rotation of COMplexes in Electric Power Systems", News STC Unified Energy System, Moscow, Russia, No. 1, Vol. 78, pp. 6-10, 2018.

[12] "FACTS Technology - State of Art, Current Challenges and the Future Prospects", IEEE, pp. 392-395, 2007.

[13] D.R. Shakurov, R.R. Teregulov, "Reactive Power Compensation", Ufa State Aviation Technical University, Ufa, Russia, No. 3, Vol. 3, pp. 10-12, 2016.

[14] A.M. Hashimov, H.B. Guliyev, A.R. Babaeva, "Improved Control Algorithm for Shunt Reactors Using Fuzzy Logic", Rudenko International Conference on Methodological Problems in Reliability Study of Large Energy Systems (RSES 2018), Irkutsk, Russia, July 2-7, 2018.

[15] M. Ahmed, Z. Fatima, M. Cherif, D.E. Kamel, "Study, Analysis and Simulation of a Static Compensator D-STATCOM for Distribution Systems of Electric Power", Leonarda Journal of Sciences, 2014.

[16] M.V. Leshkov, "Development and Research of Static Reactive Power Compensator Control of STATCOM Type for Electric Power Systems", Ph.D. Thesis, M., p. 158, 2009.

[17] K.S. Koshelov, M.V. Leshkov, "Selection of Parameters of STATCOM Static Reactive Power Compensator", Electrical Engineering, No. 8, pp. 34-37, 2007.

[18] R.B. Goncharenko, F.G. Rutberg, "Application of Flywheel Units of Alternating Current for the Purpose of Stabilization of Modes in the Power System", Power Engineering, News of the Russian Academy of Sciences, No. 5, pp. 13-21, 2012.

[19] H.B. Guliyev, N.F. Zeynalov, "Methods Indemnification of Reactive Power Compensation in Electric Network for Increase of Regime Reliability of Power Supply System", Reliability: Theory & Applications, Vol. 10, No. 3, San Diego, USA, pp. 6 -15, September 2015.

[20] H.B. Guliyev, N.R. Rahmanov, "Probabilistic Modeling of Flow Distribution in the Power System with Distributed Generation and Renewable Sources", Electronic Modeling, Vol. 38, No. 5, Kiev, Ukraine, pp. 101-112, 2016.

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