

SIMULATION OF STATCOM FOR VOLTAGE QUALITY IMPROVEMENT IN POWER SYSTEM

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ABSTRACT

Voltage fluctuations caused by rapid industrial load changes have been a major concern for both power companies and customers in the area of power quality. The fast response of the Static Compensator (STATCOM) makes it an efficient solution for improving power quality in distribution systems. The analyzed system is modeled using MATLAB/Simulink Power system including a complete STATCOM model with its power circuits and its control system. The complete model is validated by field test. Static and dynamic performance of STATCOM is evaluated and voltage fluctuation mitigation studies.

Keywords: Flexible AC Transmission Distributed Systems (FACTS), STATCOM, Voltage Flicker.

INTRODUCTION

FACTS concept is based on the incorporation of power electronic devices and methods into the high-voltage side of the network, to make it electronically controllable. The concept of flexible AC transmission system consist in the realization of a system more performed through the control of the power flow and the rise of the transmission capability until the limits tolerated by the system.

FACTS devices are to increase controllability and optimize the utilization of the existing power system

capacities by replacing mechanical controllers by reliable and high-speed power electronic devices. It is known that power flow is not directly controllable and for changes the way power flow in the power system must result in change of line impedance, voltage magnitude, or phase-difference angle [1].

The active and reactive power flow, along a transmission line connecting two buses is given by:

$$P_{12} = \frac{U_1 U_2}{Z_L} \sin u \quad (1)$$

$$Q_{12} = \frac{U_1^2 - U_1 U_2 \cos u}{Z_L} \quad (2)$$

Where U_1 and U_2 are sending and receiving end voltage magnitudes, Z_L is the impedance of the line and u is the voltage phase angle difference. It can be seen from Equation (1) that the amount of the real power

transmitted over the line can be increased by increasing the magnitude of the voltages at either end, reducing the line reactance, increasing the power angle. Flexible AC Transmission System (FACTS) increase transfer

capability and provides control of one or more AC transmission system parameter.

The FACTS devices are based on the development of the power electronics such as thyristors and give the possibility to control one or more electrical parameters: voltage, current, and phase-difference angle [2]. The basic applications of FACTS-devices are power flow control, increase of transmission capability, voltage control, reactive power compensation, stability improvement, power quality improvement, power conditioning, and flicker mitigation, interconnection of renewable and distributed generation.

FACTS controllers divided into categories, which include series, shunt, combined series-series and combined series-shunt controllers. FACTS devices perform active impedance injection instead of inserting fixed impedance devices. Active impedance injection is a term used to describe either compensation achieved by injecting an AC voltage which is accomplished using a synchronous voltage source (SVS) which generates sinusoidal voltages at the fundamental frequency and has controllable amplitude and phase angle. The SVS is capable of generating or absorbing reactive power by controlling the injected voltage magnitude [3, 4].

Static Synchronous Compensator

The shunt controllers may be variable impedance. Shunt controllers such as Static Var Compensator (SVC) inject current into the system at the point where they are connected. If the injected current is in phase with the line voltage, the controller adjusts reactive power. If the current is not in phase with the line voltage, the controller adjusts active power.

Computation and control of power flow for power systems embedded with STATCOM appear to be fundamental for power system analysis and planning purposes. STATCOM can supply the capacitive and the inductive compensation and is able to independently control its output current over the rated maximum irrespective of the amount of ac system voltage. Thus, the STATCOM can provide full capacitive-reactive power at any system voltage and STATCOM output voltage can be regulated such that the reactive power of the STATCOM can be changed.

Among all control options, control of the voltage of the local bus, which the STATCOM is connected to, is the most-recognized control function. Note that the other control possibilities have not fully been investigated in power flow analysis [5]. The STATCOM equivalent circuit shown in Figure 1 is used to derive the mathematical model of controller for inclusion in power flow algorithms.

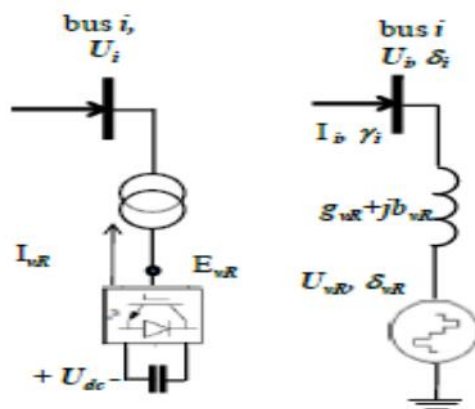


Figure 1. A schematic representation of the STATCOM and its equivalent circuit.

The power flow equations for the STATCOM are derived below from assuming the following voltage source representation [6]

$$E_{vR} = U_{vR} (\cos u_{vR} + j \sin u_{vR}) \tag{3}$$

where U_{vR} and u_{vR} is the VSC output voltage and phase angle.

According to the single line and phasor diagram in Figure 1, the power flow constraints of the STATCOM are:

$$P_{vR} = U_1^2 g_{vR} - U_1 U_{vR} (g_{vR} \cos(u_1 - u_{vR}) + b_{vR} \sin(u_1 - u_{vR})) \tag{4}$$

$$Q_{vR} = U_1^2 g_{vR} - U_1 U_{vR} (g_{vR} \sin(u_1 - u_{vR}) + b_{vR} \cos(u_1 - u_{vR})) \tag{5}$$

Where: g_{vR} and b_{vR} is the VSC conductance and susceptance respectively. Note that the active power flow between the AC source and the VSC is controlled by the phase angle u_{vR} , and the reactive power flow is determined mainly by the magnitude of the voltage source, and the VSC output fundamental voltage, U_{vR} .

Flicker

Power quality concept describes the quality of the supplier voltage in relation to the transient breaks, falling voltage, harmonics and voltage flicker. Voltage fluctuations are systematic variations of the voltage envelopes or a series of random voltage changes, the magnitude of which does not normally exceed the voltage ranges of 0.9 to 1.1 p.u. The term flicker is derived from

$$\frac{\Delta U}{U_n} = \frac{R \cdot \Delta P + X \cdot \Delta Q}{U_n^2} \tag{6}$$

Where: ΔP and ΔQ are the changes in active and reactive power; U_n is the nominal voltage; and R and X are resistance and reactance. Since R is usually very small in comparison to X , ΔU is proportional to Q (reactive

the impact of the voltage fluctuation on lamps such that they are perceived by the human eye to flicker. Technically, voltage fluctuation is an electromagnetic phenomenon while flicker is an undesirable result of the voltage fluctuation in some loads. Voltage flicker is caused by an arc furnace, one of the most common causes of voltage fluctuations on utility transmission and distribution systems [7, 8, 9]. Voltage flicker on lighting or television apparatus must be limited to avoid disturbances to human eyes (e.g., for voltage variations greater than approximately 1.5% at a frequency of 10 Hz).

The flicker signal is defined by its r.m.s magnitude expressed as a percent of the fundamental. The relative voltage drop is expressed by Equation (6):

power). Therefore, voltage flicker depends on reactive power control.

Simulation Model for Flicker Analysis [10, 11]

A MATLAB based program was developed for the flicker analysis of electrical power systems.

Simulation model for flicker analysis in electrical power systems, shown in Figure 2. Model parameters.

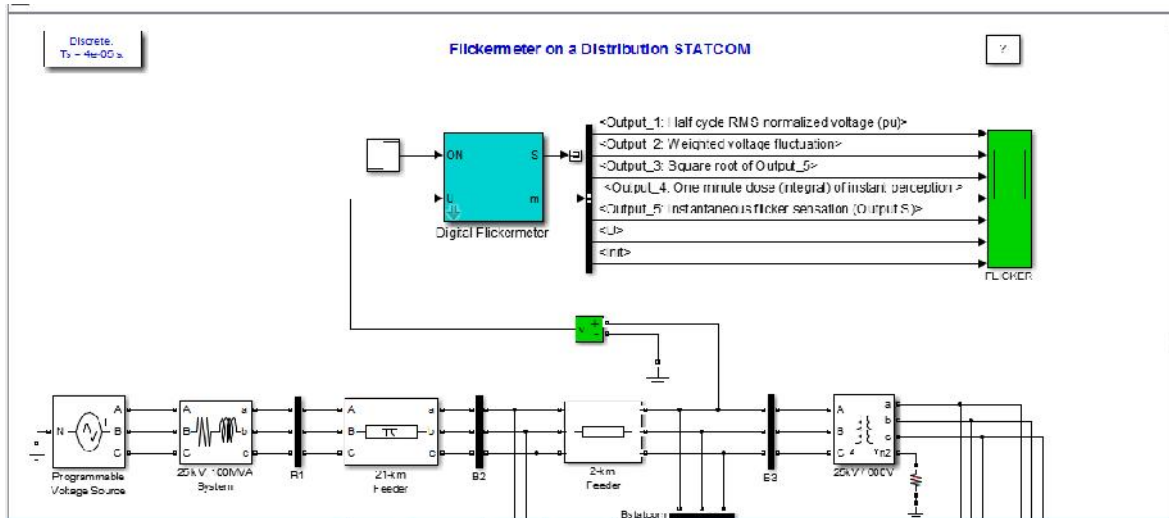


Figure 2: MATLAB simulation model for flicker analysis

The STATCOM regulates voltage by absorbing or generating reactive power. This reactive power transfer is done through the leakage reactance of the coupling transformer by generating a secondary voltage in phase with the primary voltage. This voltage is provided by a voltage-sourced inverter. When the secondary voltage is lower than the bus voltage, the STATCOM acts like an inductance absorbing reactive power. When the secondary voltage is higher than the bus voltage, the STATCOM acts like a capacitor generating reactive power.

The STATCOM consists of the following devices:

1. Coupling transformer which ensures coupling between the PWM inverter and the network.
2. A voltage-sourced PWM inverter, which is replaced on the AC side with three equivalent voltage sources. Harmonics generated by the inverter are therefore not visible with this average model. On the DC side, the inverter is

modeled by a current source charging the DC capacitor.

1. The DC current I_{dc} is computed so that the instantaneous power at the AC inputs of the inverter remains equal the instantaneous power at the DC output
2. LC damped filters connected at the inverter output. Resistances connected in series with capacitors provide a quality factor of 40 at 60 Hz.
3. Capacitor acting as a DC voltage source for the inverter
4. A voltage regulator that controls voltage at bus B4
5. Anti-aliasing filters used for voltage and current acquisition.

A flicker meter device is used to measure the instantaneous flicker sensation on terminal voltage of a Statcom unit. Flicker meter block is a digital

implementation (discrete model) of the flicker meter described in the IEC 61000-4-15 standard.

The input of this device is the phase voltage that will be analyzed after the flicker meter. Output is

the instantaneous flicker sensation. Figure 3 shows voltage magnitude in point where Statcom connected

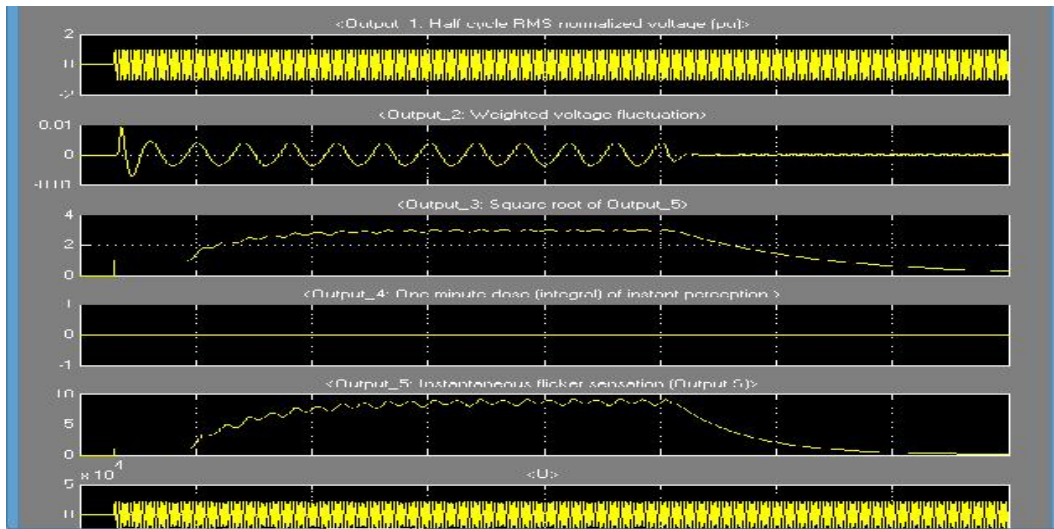


Figure 3. Representation of voltage magnitude

The variable load current magnitude is modulated at a frequency of 5 Hz. This load variation allowed observes the ability of the Statcom to mitigate voltage flicker. In Figure 4 half cycle RMS normalized voltage (p.u) and harmonics are s shown. Note that

Statcom operated in mode voltage regulation and reactive power regulation. This model is suited for observing harmonics and control system dynamic performance over relatively short periods of times (hundreds of milliseconds to one second).

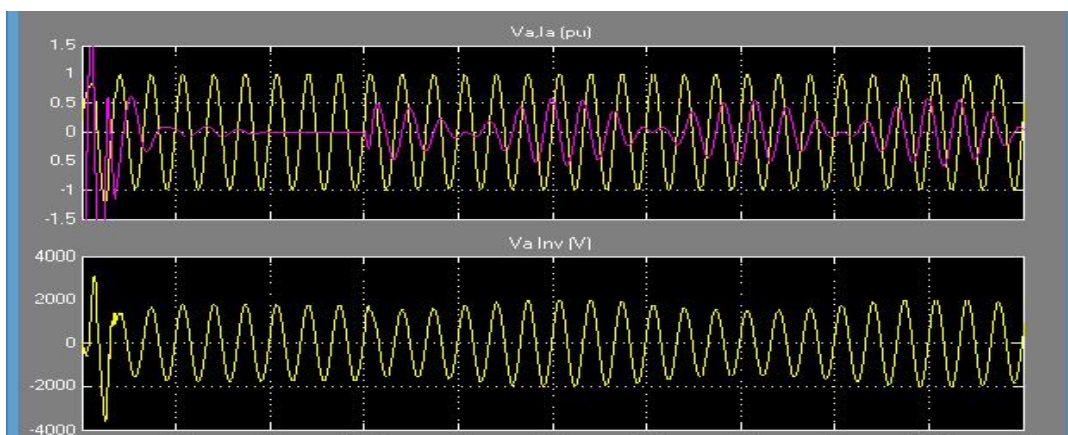


Figure 4: Real and static power waveforms

In Figure 4, it is obvious that the necessary active power storage capacity is much lower for the case of flicker control than for the case of active power control. To maintain power quality standard it is not

necessary to reach totally constant load. Thus some active power fluctuations remain when reaching the required flicker level.

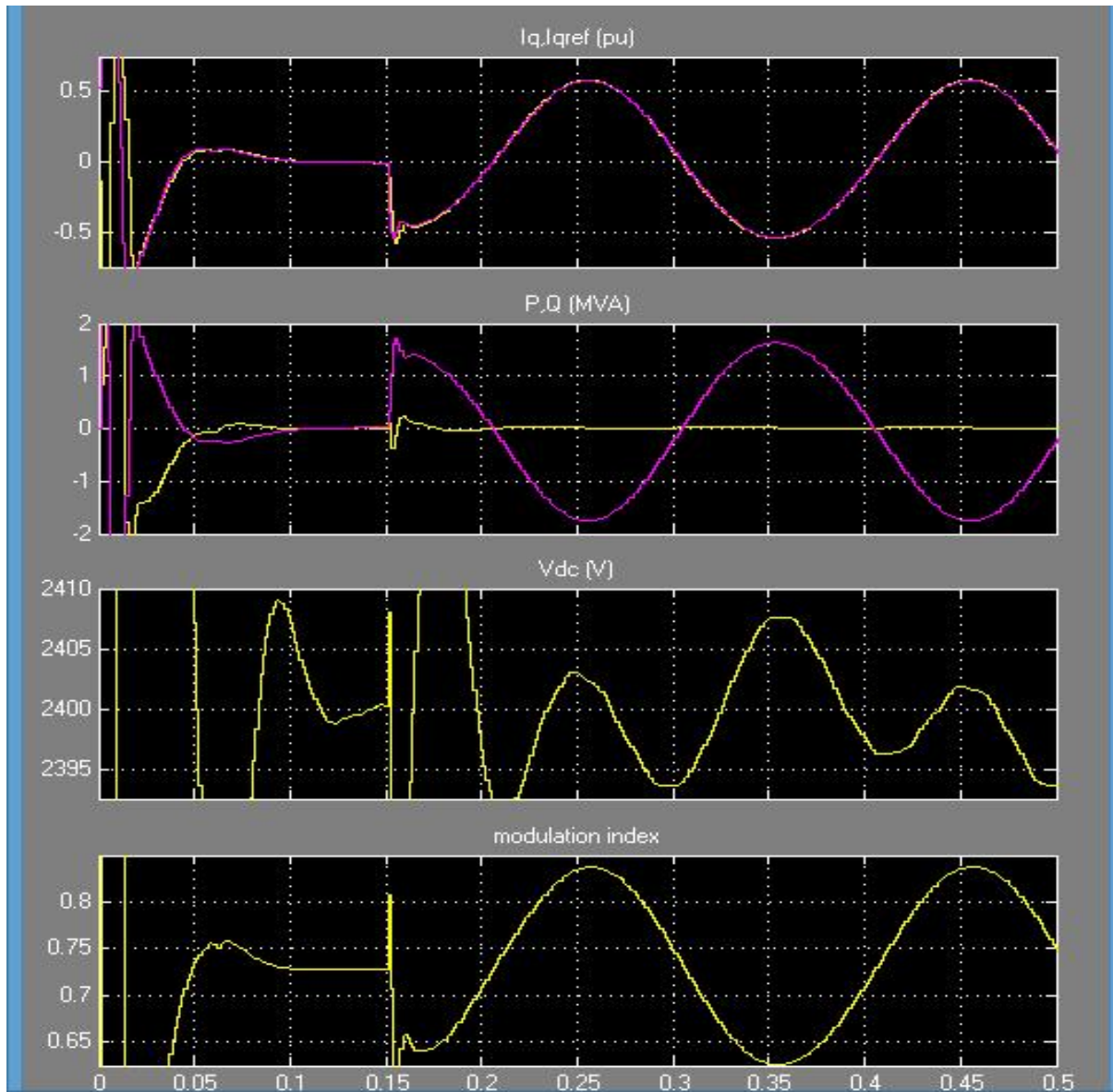


Figure 5: Output waveform of current, power, voltage and the modulated waveform from the Simulation from scope 1

The active power consumed by the system before and after the compensation and the performance of STATCOM is shown in Fig. 5. It shows that when

STATCOM absorbs and injects the active power, eliminating the negative impact of rapid changes in the

furnace during operation, the system power has a constant character.

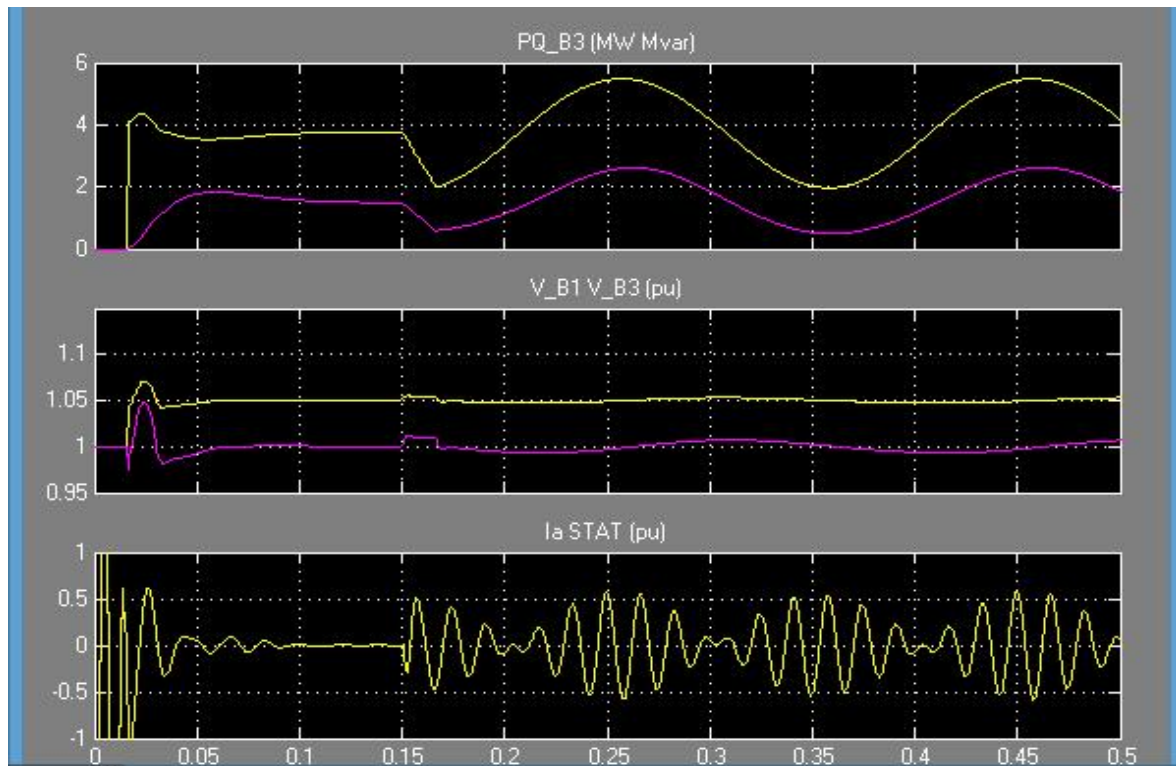


Figure 6: Output waveform of current, power, voltage and the modulated waveform from the Simulation from scope 2

Current and voltage curves in Fig. 6 shows the operation of the network inside the industrial system. The graphs present the changes before and after active power compensation. The maximum current is decreased and also the current step change in the transition from one mode to another is reduced. The voltage graph shows the increase of the average value and decrease of voltage fluctuations caused by operation.

CONCLUSION

The principle of active power compensation for voltage fluctuation and flicker mitigation is described. STATCOM with active power compensation model is introduced. This model is used for the simulation of the device impact on the system with electric arc furnaces.

1. Voltage flicker is caused by an arc furnace, one of the most common causes of voltage fluctuations on utility transmission and distribution systems
2. The analysis and simulation of a STATCOM application for the mitigation of voltage flicker problems are presented.
3. A MATLAB based program was developed for the flicker analysis of electrical power systems.

The presented simulation model represents a useful tool in energy management system. The received results show that STATCOM can reduce the voltage flicker caused by nonlinear loadings such as electro arc furnaces.

REFERENCES:

- [1] Hingorani N. G., Gyugyi L., 2000, "Understanding FACTS - Concepts and Technology of Flexible AC Transmission Systems", IEEE Press, ISBN 0-7803-3455-8.
- [2] Acha E., Fuerte C.R., Esquivel, H. Ambriz Perez, C. Angeles Camacho, 2004, "FACTS: Modelling and Simulation in Power Networks", ISBN 0-470-85271-2, John Wiley & Sons Ltd.
- [3] Balametov A. B., Halilov E. D., 2010, "Use of Flexible Alternating Current Transmission Systems as an Effective Way of Solving Problems in EPS", Problems of Energy, No. 4, pp. 20-28.
- [4] Tabatabaei N.M., Abedi M., Boushehri N. S., Jafari A., 2014, "FACTS Technology for Reactive Power Compensation and Power System Control", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 19, Vol. 6, No. 2, pp. 130-137.
- [5] Zhang X. P., Rehtanz C., Pal B., 2006, "Flexible AC Transmission Systems: Modelling and Control", Springer- Verlag, Berlin Heidelberg.
- [6] Jalilzadeh S., Darabian M., Azarim M., 2013, "Static Var Compensator Controller Design for Improving Power System Stability", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 14, Vol. 5, No. 1, pp. 44-51.
- [7] Dugan R. C., McGranaghan M. F., Beaty H. W., 1996, "Electrical Power Systems Quality", Second Edition, The McGraw-Hill.
- [8] Kelly D. D., Salem H. H., Singh B., 1992, "Reduction of Voltage Flicker of a Simulated Arc Furnace by Reactive Compensation", Electric Power Systems Research, No. 24, pp. 135-139.
- [9] Sun J., Czarkowski D., Zabar Z., 2002, "Voltage Flicker Mitigation Using PWM-Based Distribution STATCOM", IEEE Power Engineering Society Summer Meeting, Vol. 1, pp. 616-621, 21-25.
- [10] Gyugi L, Otto A. A, 1976, "Static Shunt Compensation for Voltage Flicker Reduction and Power Factor Correction", American Power Conference, pp. 1272-1286.
- [11] Bertola A., Lazaroiu G. C., Roscia M., Zaninelli D., 2004, "A Matlab-Simulink Flicker Meter Model for Power Quality Studies", IEEE PES 11th International Conference on Harmonics and Quality of Power, Lake Placid, USA.