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SIMULATION TOOL FOR FACTS CONTROLLERS- "A REVIEW"

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ABSTRACT

This paper is an effort to summarize the application and effect of simulation tools used for testing and design of FACTS Controllers. Simulation software and program are powerful and effective tools and their application helps in technological upliftment and rapid enhancement in the field of electrical and electronics engineering. This paper presents various simulation tools for teaching and research purposes in the area of FACTS Controllers. This paper provides a modeling and simulation of different FACTS controllers based on papers published in journal and conference, implemented in simulation software such as MATLAB, Simulink, EMTDC/PSCAD,PSAT etc.

INTRODUCTION

Prior to the development of simulation software and simulation models**,** it had been very complicated to analyze and study the operation of complex power systems (Povh, Retzmann, 2004), Simulation software gives the accurate analog of physical systems that exists in the real world (Rahul Agrawal, 2013). Simulation provides a way in which alternative design can be evaluated without having to experiment with a real system, which may be costly, time-consuming, or simply impractical to do. The gradual development of digital computer enhances the accuracy and operation of simulation software in the area of engineering and technology (Rahul Agrawal *et al*., 2013). The Flexible AC Transmission System (FACTS) controllers are power electronics based devices used for controlling of AC transmission system parameters such as line impedance, phase angle, voltage etc. (Hingorani and L. Gyugyi, 2000). FACTS controller is classified into three types- Series Controllers, Shunt Controllers and Combined Series and Shunt Controllers (Hingorani and L. Gyugyi, 2000; Song and A.T. John, 1999; Kothari, I.J Nagrath, 2012 and Mathur and R.K. Varma, 2002).

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STATCOM and SVC are classified as shunt controllers whereas SSSC, IPC and TCSC are series controllers. UPFC, IPFC and TCPST are the example of Combined series-shunt controllers. FACTS Controllers are used for power control, voltage control, reactive power compensation, stability, and system security (Hingorani and L. Gyugyi, 2000; Song and A.T. John, 1999; Kothari, I.J Nagrath, 2012**).** Simulation technology presents efficient planning and operation of power systems including High Voltage Direct Current (HVDC) and FACTS controllers. With the use of advanced simulation software, it has become possible to study dynamic behavior and performance of FACTS controllers. Computer simulation of FACTS controllers allows satisfactory explanation of its operation (Rahul Agrawal, 2013). The use of simulation tools offer the following advantages

- Saving of time as a response is faster.
- Inexpensive as compared to real prototype model.
- The space requirement is less.
- Better optimization investigation.

The simulation software presented in this paper is also used in the area of engineering and technology. Papers on the IEEE Xplorer with simulation software discussed in this paper are shown in Table 1.

Table 1. Papers on IEEE Xplorer with Simulation Software

S. N0.	Name of Software	Paper on IEEE Xplorer
1	MATLAB	28666
2	PSPICE	2777
3	PSACD	2688
4	EMTDC	1840
5	RTDS	884
6	PSIM	834
7	PSAT	234
8	EMTP-RV	130
9	ETAP	88
10	MATPOWER	69
11	NETOMAC	41

From the Table 1 it is evident that MATLAB is the most widely used software for research and teaching.

Agrawal *et al*. (2013), presented the key feature and advantage of the software listed in Table 1. The review paper on simulation tools for FACTS controller have not been discussed in existing literature.

Simulation Tools for FACTS Controllers

MATLAB / SIMULINK: MATLAB is a high level programming language having an interactive environment for visualization and technical computation, and SIMULINK (www.mathworks.com), is a tool for modelling, simulating, analyzing and designing dynamic systems. MATLAB performance can be expanded with the addition of Simulink. The features of MATLAB/Simulink for the simulation and modelling of power systems and power electronics circuits is discussed in (Arun Sekar, 2005 and Visnic, 2011). MATLAB and Simulink are widely employed in industries, technical and research institutions. Metwally *et al*. (2008) presented optimal location of SVC in power system using GA for handling the optimization problem. Kumkratug *et al.* (2007) discussed the load injection model of VSC based FACTS devices like STATCOM, SSSC and UPFC on MATLAB/Simulink. The model is tested on the New England system. Ref. [44] discusses the dynamic models of power system using FACTS controllers such as STATCOM, SSSC and UPFC by using a synchronously rotating q-d frame of reference. The model is tested on the Western System Coordinating Council (WSCC) test system. Ref. (Chengaiah, 2012), presents the simulation of UPFC model connected with the single and double transmission line 6.6/22 kV using MATLAB/Simulink. The performance of transmission line with UPFC for power quality improvement is analyzed.

Ref. (Adel M Sharat, 2012) discusses a FACTS based switched capacitor banks controlled by multi-loop dynamic decoupled error driven controller. This scheme is used for smart grid applications for increasing bus voltage stabilization, improving voltage regulation and power factor and limiting inrush current. In (Santiago-Luna *et al*., 2006) Evolutionary Programming (EP) was used to improve the angle stability of single machine infinite bus system with SVC and PI controller. The optimal reactive power flow based STATCOM to minimize the power loss of 3-bus test system is proposed by (Uthitsunthorn, 2010) Ref. (Lashkar Ara *et al*., 2012), proposed the Nonlinear Programming (NLP) and Mixed Integer Nonlinear Programming (MINLP) for optimal location of UPFC and Phase Shifting Transformer (PST) using MATLAB and General Algebraic Modeling System (GAMS). The switching level based simulink model of IPFC to regulate the power flow is demonstrated in (Muruganandham, 2012). An ANFIS based model of single machine infinite bus system with the SSSC to improve the transient stability is given by (Swasti R. Khuntia, 2013). Ref. (Prashant Kumar Tiwari, 2009) proposed GA with NR power flow method to minimize overall system cost includes generation cost and the investment cost of TCSC and SVC in IEEE-30 bus and IEEE 118 Bus system. They also calculate active power generation for several loading conditions. Simulation results, are carried on MATLAB programming. Ref. (Iraj Kheirizad, 2008) proposed Hybrid GA-PSO for optimal location of SVC with MATLAB programming. To alleviate small signal oscillation problems in a multi machine system using PSO to find the location and setting of TCSC and SVC is reported in (Mondal, A. Chakrabarti, 2012) In (Abou El Ela, 2010). Ela *et al.* presents an evolutionary-based approach, differential evolution (DE) to solve the optimal power flow (OPF) problem and it is tested on the IEEE 30-bus test system for cost minimization, voltage stability enhancement and voltage profile improvement. The investigation with thyristor-controlled series capacitor (TCSC) and thyristor controlled phase shifter (TCPS) with DE for minimizing the generator fuel cost were reported by Basu (Basu, 2008). Panda investigates the design of TCSC for the enhancement of power system stability using DE (Sidhartha Panda, 2009) and NSGA-II (Sidhartha Panda, 2010). In (Krishnaveni *et al*., 2007) Artificial Neural Network controller based Unified power flow controller (UPFC) is used for power flow control by injecting the series compensating voltage. The table 2 presents the heuristic optimization technique discussed by different researchers with FACTS using MATLAB.

MATPOWER: Matpower is a package for solving power flow and optimal power flow problems (Ray Daniel Zimmerman, 2011; http://www.pserc.cornell.edu/matpower and Mudathir, 2009). Matpower is MATLAB based open source software. Ref. (Santiago-Luna, 2006) deals with the technique for optimal placement of FACTS controllers in a power system network using Evolution Strategies and simulation for the power flow study is carried out using MATPOWER software. Ref. (Natalia, 2012) developed the steady state model of IPFC to control the power flow in the transmission line.

In (Bongkoj Sookananta, 2009) Differential Evolution (DE) is presented for the optimal allocation of TCSC. MATPOWER is used for the simulation of the IEEE 5 bus and IEEE 24 bus RTS system. The Result of DE shows the superiority over the GA and sensitivity index based methods. Mahdad *et al.* [40] proposed the GA based SVC model for the IEEE-30 bus system. The model is validated for the different loading condition to minimize the fuel cost and reactive power of the system.

PSB: It is a graphical tool associated with MATLAB/SIMULINK environment for the simulation of power system (Sybille, P.Brunelle, 2000) Ref. (E1-Zonkoly, 2008) deals with the modelling of SSSC by using PSB and

Simulink software. The objective of the study is to minimize transmission losses in power network by the optimal sizing of SSSC controllers. Somsari *et al*. (Kittaya Somsari, 2013) presented the modeling and design of the load voltage controller including D-STATCOM controller for load voltage regulation. The proposed model and D-STATCOM controller design is simulated on MATLAB Power System Blockset. The application of PSB in the simulation of electric circuits, power electronic devices, electric drives and power system is witnessed in (Louis-A Dessaint, 1999). The investigation of SSSC with GA to improve the transient performance of the three machine power system was reported by Panda (Sidhartha Panda, 2009). 2005) investigate the optimal utilization of UPFC for enhancing power transfer capability. For the sake of comparison in power quality and cost efficiency, an analysis between FACTS and HVDC are also discussed. In (Nagesh and P. S. Puttaswamy, 2012) continuous power flow is used to determine the voltage stability of the standard IEEE-14 system with SVC. In (Wartana, J G Singh, 2012), a PSO technique has been developed for enhancing the loadability, minimize the TCSC device cost and active power losses of the Java-Bali 24-Bus Indonesian system.

NETOMAC: Network Torsion Machine Control (NETOMAC) is developed by (http://simsen.epfl.ch).

Table 2- Heuristic Optimization Technique with FACTS using MATLAB

S. No	Heuristic Optimization Tech.	Types of FACTS controller	Objective Function	Test System	Reference
1	Particle swarm Optimization (PSO)	TCSC, SVC, UPFC	Loadability , installation cost of FACTS devices	IEEE-6 and IEEE-30 bus system	106
2	Differential Evolution (DE) and GA	TCSC	Security	IEEE-6 and IEEE-14 bus system	107
3	DE and GA	TCSC	Minimize active power loss	IEEE-3, 5 and 14 bus system	108
4	PSO and GA	TCSC	Minimize active power loss	IEEE 3, 5 and 14 bus systems	109
5	PSO and GA	TCSC	Maximize system loadability	IEEE-6 and IEEE-30 bus system	110
6	NSGA-II	TCSC	To reduce power loss, investment cost and to improve security margin and ATC	IEEE-30 bus system	111
7	Evolutionary Programming	TCSC, TCPS, UPFC and SVC	To enhance the total transfer capability (TTC)	IEEE 30-bus system	112
8	GA	UPFC	Reduce the total generation fuel cost	IEEE-14 system	113
9	GA	TCSC	Security margin	IEEE 30-bus system	114
10	GA	TCSC, TCPST	Line Overloading	IEEE 30-bus system	115
11	GA	TCSC	Reduce system losses and cost of generation	IEEE 30-bus system	116
12	GA	TCSC	Fuel cost minimization and active power loss minimization	IEEE 30-bus system	117
13	Evolutionary Programming	UPFC	Power loss minimization	Modified IEEE 30- bus system	118
14	PSO	TCSC,UPFC, SVC	Installation cost of FACTS devices and system loadability	IEEE 6, 30 and 118 bus systems and Tamil Nadu Electricity Board (TNEB) 69 bus system	119
15	PSO	TCSC and UPFC	Installation cost of FACTS device, Severity of overloading	IEEE-6 and IEEE-30 bus system	120
16	NSGA-II	TCSC, TCPS	Fuel cost, Emission, Loss	Modified IEEE 30-bus and 57-bus test systems	121

Table 3. Other Simulation Software used in FACTS

S. N0.	Name of Software	FACTS Controllers	Objective	Reference
1	SIMFACTS	UPFC, TCSC, SSSC, SVC, STATCOM	Power Flow Equation	97
2	MIPOWER	Series FACTS Controller	Trasient Stability Analysis	98
3	SABER	SVC, TCSC, UPFC	Interaction of wind farm with FACTS	99
4	SIMSEN	UPFC	Steady state and transient behavior	100
5	EUROSTAG	SVC, STATCOM, UPFC	dynamic stability	101
6	UWPFLOW	STATCOM and SVC	Effects of A Wind Farm and FACTS Devices on Static Voltage Stability	102
7	Power Flow Analysis and Control (PFAC) software	SVC	Power Transfer Capacity Enhancement	103
8	PSASP	UPFC	Total Transfer Capability	104
9	NEPLAN	STATCOM and SVC	Total Transfer Capability	105

PSAT: This simulation package is used for analysis and control of electrical power system (www.uclm.edu/area/gsee/Web/Federico/psat.html and Federico Milano, 2005) Ref. (Nagesh, 2012) presents the enhancement of voltage stability using SVC**.** The study uses standard IEEE-14 bus test system with base case and SVC, are demonstrated using PAST. Yap *et al*. (Yap, M.Al-Dabbagh, It is used for simulation of the steady state and transient behaviour of power system (Kulicke, 1979) Povh *et al.* (Povh, Retzmann, 2004) discussed the benefit of NATOMAC for large power system and system interconnection. The Optimization and coordinate control of TCSC and SVC using NATOMAC is demonstrated in (Lei, D. Povh, 2000). The per unit and power system damping model of UPFC is investigated in (Wei Shao, 2001). The model improves stability and damps the power system oscillation. A new model of TCSC with a non linear control strategy for improving transient stability and damp power system oscillation for single machine infinite bus system is witnessed in (Jiang, 2000). The feedback linearization technique is used to transform non linear model to a linear model. Papic (Papic, 2000) have studied the voltage source converter based phasor equivalent model of UPFC for transient stability. Pavic (Papic, 2000) also suggest the model of DSTATCOM and DVR in the NETOMAC with energy storage element to mitigate the power quality problems. Mihalic *et al*. (Mihalic, 1996) presented the NETOMAC based mathematical model of UPFC for enhancement of transient stability. Xiaobo *et al* (Xiaobo Tan, 1998), have analyzed the fuzzy based T-S model of TCSC to improve damping and transient stability. The nonlinear model of TCSC is modelled as linear by fuzzy blending.

ETAP: This software is used for designing and analysis of all stages of power system and smart grid (www.etap.com) ETAP has better, strong and proven analysis algorithm which adds flexibility to complete modeling environment and operator-friendly user interface. In (Guneet Kour, 2012) the authors have examined the simulation of distributed substation with SVC in ETAP environment for enhancing bus voltage and power transfer capability. Slochanal *et al*. (Slochanal, 2005) proposed the simulation model of UPFC with load flow. In (Katria, 2009) simulation of SVC is performed to improve the voltage, power factor and minimize the loss.

EMTP-RV: It is a latest advanced version of EMTP. It is a professional tool for simulating and analyzing the transients in electrical power networks. It finds applications in power system, Electrical machine, multi-terminal HVDC system and simulation of FACTS controllers (www.emtp.com), Shah *et al*. (Nikunj M Shah, 2008) analyzed the steady state and transient behavior of Chain link STATCOM. Deng *et al*. (Deng, 2005) presents the VSC based simulation model of STATCOM. The PWM based DC to AC converter is used for the study. The STATCOM model with variation in load, reactance and DC capacitor voltage is shown in (Salem, 2006) Faried *et al*. (Fried, 2010) developed time domain simulation model of STATCOM for power system stability improvement in multi machine system. The selective pole switching is used for the phase compensation. The investigations with a time domain model of STATCOM for damping sub-synchronous resonance was reported by Rai *et al*. (Rai, 2009). The STATCOM is operating in a phase imbalance mode to damp the torsional oscillation. In (Rai, 2011) SSSC and series capacitor are used to damp out the sub-synchronous resonance. The modelled is validated on the different loading condition with faults in the system.

PSCAD/ EMTDC: PSCAD/ EMTDC are a simulation tool used for simulation, design, analysis, optimization and verification of power systems, power electronics and electrical machines (Shanshan Yang, 2013; https://hvdc.ca/pscad; http://www.simulation-esearch.com and PSCAD, 2010). Ref. (Amiri, Mo. Amiri, 2008) proposed the simulation of Distributed-FACT by using PSCAD/EMTDC. Ref. (Jong-Su Yoon, 2006), presented the transient simulation model of UPFC in the SSSC operation mode of the KEPCO (Korean Electric Power Corporation) power system. Performance of UPFC using PSCAD/ EMTDC is discussed in (Tara Kalyani, 2008) Ref. (Yang Ye; Kazerani, 2005) discussed the modeling of current source converter based STATCOM. Ref. (Marei, 2003) developed the model of STATCOM for compensation of reactive power based on the Current Regulated Pulse Width Modulation (CRPWM) inverter. The performance of SVC and TCSC for damping SSR is witnessed in (Varma, 2008). Ajami *et al*. (2006) suggested a transient model of center mode UPFC to regulate the active power, reactive power and voltage of the transmission line. In (Mihalic, 1998) authors simulate and compared the power oscillation damping of Controllable series compensation (CSC) and a SSSC based on their mathematical model, and found that SSSC is superior than the CSC. The power flow control scheme based UPFC and IPFC is witnessed in (Yang Ye, 2006)

RTDS: The RTDS is a fully digital electromagnetic transient power system simulator, which provides simulation of electrical power system with fast response, reliability and accuracy (Rahul Agrawal *et al*., 2013 and www.rtds.com). Ref. (Tarlochan Singh Sidhu *et al*., 2005; Albasri *et al*., 2006] presents the performance of distance protection on shunt FACTS compensated transmission lines using RTDS. Modelling and simulation of FACTS devices (SVC and STATCOM) is done by EMTDC simulation package (Tarlochan Singh Sidhu, 2005) Ref. (Dong Shen *et al*., 1998 and Xiao Xiangning *et al*., 2008) present the use of an RTDS simulator for the testing the performance of an SVC controller. Ref. (Khederzadeh *et al*., 2006) presents the impact of TCSC on the protection of transmission lines. Ref. (Zhao Yang, 2008) proposed the modelling of Single machine infinite bus power system including SSSC.

PSIM: It is one of the best simulation tool, especially designed for power electronics and electrical motor control. The FACTS controller circuit can be designed with fast simulation. It can interface to MATLAB/SIMULINK to access complete mathematical power of MATLAB (Sameer Khader, 2011 and www.powersim.com). Masood *et al.* (Tariq Masood Ch *et al*., 2007) demonstrated the dynamic performance of state space based FACTS controllers (STATCOM, SSSC and UPFC) in multiple operations using PSIM / MATLAB digital control simulator. Singh *et al.* (Rupal Singh *et al*., 2012) describe a simulation model of Distribution STATCOM (DSTATCOM) by using PSIM for power quality improvement.

PSPICE: It is a modified PC version of SPICE. It finds wide application in power electronics and electric drive systems [31], analog and digital systems. Karthik (Karthik *et al*., 2012) considers the model of VSC- based IPFC in multi line transmission system for series compensation. Model is also improving the power flow and power balance of the transmission system. Sankar *et al*. (Sankar *et al*., 2010) deals with the simulation of different FACTS controllers such as FC-TCR, TCVR and UPFC using simulation software PSPICE. FC-TCR is used to control active and reactive power flow, whereas for voltage regulation TCVR and UPFC is employed. The time domain model of STATCOM with state space equation is proposed in (Bina, 2005). The model is able to control both voltage and reactive power. In this paper eleven simulation software's are discussed. Apart from the simulation tools discussed , there are many other simulation software such as SIMFACTS, CASPOC, SABER, MIPOWER as listed in table 3, are not be discussed in detail due to limited availability of research papers on FACTS devices.

Conclusion

This paper summarized the application of simulation softwares used in the flexible AC transmission system. These simulation softwares are asset in teaching UG and PG courses of power systems. The paper also provides the brief knowledge base of simulation tools. The information about simulation software presented in this paper act as a potential source of information for research scholars in the field of power systems and FACTS controllers. In this paper optimization technique along with simulation software also presented.

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