International Journal of Electrical, Electronics and Computer Engineering **2**(2): 91-96(2013) **ISSN No. (Online): 2277-2626**

An Educational and Professional Simulation Tools in Power Systems and FACTS controllers- "An Overview"

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(Received 1 September, 2013 Accepted 19 September, 2013)

ABSTRACT: This **paper is an attempt to summarize and discuss the simulation tools used for analysis, design & testing of Power Systems and FACTS Controllers. FACTS devices are power electronics based components; simulation tools for power electronics circuits are also discussed. The application of simulation software and program offers a powerful tool in the technology of electrical & electronics engineering. During the last two and half decades, off-line and real-time simulation tools gained popularity to carry out of the successful operation of the power systems and FACTS controllers. This paper presents various simulation tools for teaching and research purposes. Apart from the simulation tools discussed here, there are many other simulation programs for power systems and FACTS Controller. The report also discusses a short introduction about FACTS controllers, their features, importance and their need in power systems.**

Keywords: *FACTS Controllers, Simulation, MATLAB, Power systems, RTDS,EMTDC,MiPower*

NOMENCLATURE

FACTS- Flexible AC Transmission System
HVDC- High Voltage Direct Current
GUI- Graphical User Interface
GASP- General Activity Simulation Program
MATLAB- Matrix Laboratory
SIMULINK- Simulation Link
MatDyn- Matlab Dynamic
PSAT- Power System Analysis Toolbox
NETOMAC- Network Torsion Machine Control
ETAP- Electrical Transients & Analysis program
EMTP-RV- Electromagnetic Transients Program Restructed Version
EMTDC- Electromagnetic Transients including DC
PSCAD- Power System Computer Aided Design
RTDS- Real Time Digital Simulator
PSIM- Power Simulator
PSPICE- Personal Computer Simulation Program with Integrated Circuit Emphasis

I. INTRODUCTION

Simulation tools for power systems and FACTS controllers employed in research, analysis, planning, designing and teaching are helpful in the realization of the structure before going through practical tests. With the help of simulation software system engineers can improve modeling techniques to attain the required objective.

FACTS controller is power electronics based devices which are employed for controlling of single or more AC transmission system parameters (such as line impedance, phase angle, voltage etc.) [1]. There are three types of FACTS controllers- Series Controllers, Shunt Controllers & Combined Series & Shunt Controllers [1-4].

Static Synchronous compensator (STATCOM), Static Var Compensator (SVC), Thyristor Controlled Reactor (TCR), FC-TCR, Thyristor Switched Reactor (TSR) & Thyristor Switched Capacitor (TSC) are classified as shunt controllers whereas Static Synchronous Series Compensator (SSSC), Interphase Power Controller (IPC), Thyristor Controlled Series Capacitor (TCSC), Thyristor Switched series Capicator (TSSC), Thyristor Controlled Series Reactor (TCSR) & Thyristor Switched series Reactor (TSSR) are series controllers. Combined series-shunt controllers are Unified Power Flow Control (UPFC), Thyristor Controlled Phase Shifting Transformer (TCPST) & Interline Power Flow Controller (IPFC). FACTS Controllers are used to improve voltage profiles, enhance power transfer capability, power quality, loading capacity of the lines, stability, security & transmission efficiency [1,3]. Some additional merits reduce loop flows, transmission losses, limit short circuit current, mitigates sub synchronous resonance and reactive power compensation. FACTS controllers are the best choice for greater flexibility & controlling of power in modern power systems and interconnections of grids [4].

Simulation technology offers efficient planning & operation of power systems including HVDC & FACTS. With the use of advanced simulation software, it has become possible to study dynamic behavior & performance of FACTS controllers in a fast & accurate way. Computer simulation of FACTS controllers allows satisfactory explanation of its operation. This helps in improving the features of FACTS controllers. This paper presents many powerful simulation tools like NETOMAC, RTDS, EMTP, PSCAD/EMTDC, Mipower, MATLAB/Simulink, etc.

Good simulation tools must have following features:

(i) Simplicity
(ii) Comfortable and user friendly.
(iii) Freedom to choose the right models for the elements.
(iv) Ability to correct errors.
(v) Accuracy of the system solutions should be up to mark especially when sensitive power electronics FACTS devices are introduced.
(vi) Instinctive user interface.
(vii) All FACTS devices & controller should be included in components library.
(viii) Adequate ability to model large power systems.
(ix) Output of simulation execution should be within the constraints.

II. SIMULATION TOOLS

Simulation software gives the accurate replicate of all physical effect that exists in the real world. Simulation provides a way in which alternative design or plan can be evaluated without having to experiment with a real system, which may be prohibitively costly, time-consuming, or simply impractical to do.

Before the development of simulation tools and simulation models**,** it was very difficult to analyze and investigate the operation of complex power systems [17]. The early designs were very complex and slow, and possessed memory in the limited range. The gradual development of digital computer enhances the accuracy and utilities of simulation softwares in the area of space, biomedical, electrical, electronics, computer science, mechanical engineering and technology. However, our discussion is limited to software used in the field of electrical engineering.

By developing new model systems, simulation programs, the quality of both analog and digital simulation has been improved and enhanced. Currently simulation tools are equipped with realistic portrayal of actual conditions of a system in a real time. This makes simulation results capable of giving a highly reliable forecast.

Simulation tools are classified as Off-line & Real-time [6]. Off-line simulation tools have easy installation and access to generic computer systems. They are readily incorporated with the working environment and friendly with user's operating system as well. PSCAD, PSS/E, PSAPAC, EUROSTAG & EMTDC are some of the examples of Off-line simulators.

Real time simulators are efficient to provide results in synchronism with a real time clock. They have ability to integrate with physical devices & manage data exchanges with the real-time clock. There are several commercially available real-time digital simulators such as RTDS [7], HYPERSIM [8], and RT-LAB [9], NETOMAC. Need of simulation technology has increased with the rise of complexity of networks. In present scenario, the simulation tools for electrical systems have achieved a very high level. The features of real time simulators with excellent programs are constantly improving. They are easily accessible in the market [17].

Benefits of the simulation tools are:

1. Time Saving and inexpensive.
2. Detect error very fast
3. It requires less space.
4. Easy to realize, also model is designed in simulation environment which reduce real prototype.
5. Better & speedy optimization analysis.

As stated earlier great number of simulation tools are available having both merits & demerits. At present, generally two types of inputs are provided by simulation tools [5]. They are:

a. **Graphical input:** The elements of the circuit of the FACTS controller are fed into computer graphically by using simulation packages.
b. **Mathematical input**: This case involves the simulation of mathematical derivations & descriptions of the device which is fed into a computer.

III. SIMULATION TOOLS FOR POWER SYSTEMS AND FACTS ONTROLLERS

1. MATLAB: MATLAB was developed by Mathswork [10]. It is a high level programming language having an interactive environment for visualization & technical computation. By using MATLAB matrix calculations, plotting of function & data, creation of models, algorithm & user interfaces can be done. MATLAB interfaces with programs in other languages like C, C++, FORTRAN and Java. Other applications of MATLAB are signal processing & communications, control systems, test & measurements, computational finance & biology, video & image processing. The modeling, analyzing & designing of FACTS controllers can be easily done by Matlab software. MATLAB is widely employed in industries, technical & research institutions. The current version of MATLAB is R 2012 b.

2. SIMULINK: SIMULINK [10], an interactive tool for modelling, simulating, analyzing and designing dynamic systems. SIMULINK offers a set of tools that can be used to build systems from the library of built-in blocks. It is also allows creation of custom blocks that can incorporate C/C++, FORTAN, JAVA or MATLAB code. It integrated with the rest of MATLAB environment. MATLAB performance can be expanded with the addition of Simulink. The features of MATLAB/Simulink for the simulation & modelling of power systems & power electronics circuits is discussed in [19, 20].

3. MATPOWER: The E&CE group of Cornell University, Ithaca, New York developed the Matpower in 1999. Matpower is a package for solving power flow & optimal power flow problems [11, 12]. It can be easily used, understand and modify by researchers & educators.

It is designed for keeping the code simple to understand & modify to give the best performance possible. Matpower is a free & an open source package of MATLAB files, runs on MATLAB. Matpower uses all the standard AC & DC models for optimal power flow analysis. The current stable version of MATPOWER is 4.1.

Stijn Cole and Ronnie Belmans [21] discussed about the easily available open source Matlab based software called MatDyn for the simulation of power systems. Another Matlab based software packages employed for the simulation of power system have been originated by others. Their features are nicely summarized in a [13].

4. PSAT: PSAT is developed by Prof. F Milano, in 2002. The PSAT is used for analysis & control of electric power system [14]. Its main features include load Flow analysis, Stability Analysis, FACTS controller models. The current stable version of the PSAT is 2.16.

5. NETOMAC: Network Torsion Machine Control (NETOMAC) is developed by Siemens [15]. It is a large integrated power systems software simulation system used for simulating & analyzing electric power systems [16]. It supports simulation of electrical network in the time domain as well as frequency domain. It finds wide application in designing & analyzing the behavior of control system & power networks. D. Povh *et al.* [17] discussed the benefit of NETOMAC for large power system & system interconnection. It provides following features:

(i) Steady state load flow & short circuit calculations.
(ii) Analysis of frequency range & Eigenvalue.
(iii) Optimization & parameter identification.
(iv) Real time testing & simulation.

P. Lehn *et al.* [23] describes the efficient features as well as limitations of both EMTP & NETOMAC programs for simulation of HVDC. Comparative study of the features of NETOMAC & EMTP against transient models is also discussed.

6. ETAP: This program is used for designing & analysis of power system and smart grid. ETAP has better, strong & proven analysis algorithm which adds flexibility to complete modeling environment & operator-friendly user interface. ETAP is widely used in all the stages of power system, i.e. generation, transmission, distribution & utilization. Its unique features make it the best simulation tool for continuous monitoring, simulation & optimization of the system. Keith Brown *et al.* [24] introduces simulation tool ETAP with its wide applications, techniques & unique features. It is employed for interactive simulation of power system & also performs numerical computations with great speed. The latest version of ETAP is 7.0 full & 7.1 demos [18].

7. EMTP-RV: It is the latest advanced version of EMTP. It is a professional tool for simulating & analyzing the transients in electrical power networks. It finds applications in power system design tool, synchronous machine control, power electronics, switchgear & protection, transient stability analysis, multi-terminal HVDC system & simulation of FACTS controller [29]. Omar Saad [25] describes about the important role of simulation tool EMTP-RV for the simulation & analysis of electromagnetic transients (EMT) in power systems. The latest version of EMTP-RV 2.4. Following are the features of EMTP-RV [29]:

(i) Provides superior modeling, flexibility & drag-and-drop simplicity.
(ii) Fast computation & solution to very large scale problems.
(iii) Give solution to very large scale problems.
(iv) Initialization & steady state solution of control system & harmonics.
(v) Completely remove topological limitations.

8. EMTDC: It is a powerful, robust & very efficient simulation tool for power system transients [35, 36]. EMTDC is originally inspired by Dr. Hermann Dommel in the 1970's and developed by the Manitoba HVDC Research Centre. EMTDC is employed for the operation, design & modeling of power systems and power electronics. EMTDC represents & solves electric circuit by differential equations (for both electromechanical & electromagnetic system). Features of EMTDC are:

(i) Contingency analysis of AC network can be studied.
(ii) Analysis of harmonics & sub-synchronous resonance.
(iii) Relay & circuit breaker co-ordination
(iv) Design & c-ordination of FACTS devices, HVDC & variable speed drives and many more features.

9. PSCAD: It is a perfect, powerful, fast & easy to use power system simulation tool used for simulation, design, analysis, optimization & verification of power system & power electronics. It was first planned in 1988. PSCAD finds applications in electrical machines, FACTS devices, transmission lines & cables. PSCAD with EMTDC offers unique tools & models for complete & accurate analysis of electrical system [26]. GUI PSCAD is used with EMTDC to enhance its features. PSCAD uses flexible GUI while EMTDC is user defined power system software. EMTDC (with PSCAD) is greatly employed by engineers, scientists, manufacturer, utilities & technical/research institutions around the world.

Shanshan Yang and Gregory A Franklin [26] show the comparative study between PSCAD/EMTDC & EMTP-RV for the simulation & modeling of a switching transient overvoltage study in power systems. X4 (4.5) is the current version of the PSCAD simulation software [32].

10. **RTDS:** The RTDS is a fully digital electromagnetic transient power system simulator which provides simulation of power system with fast response, reliability & accuracy [38]. RTDS software supports power system, control system & protection & automation component model for simulation. It has following features:

(i) Smart grid applications.
(ii) Distributed generation of wind plants, solar plants & fuel cells.
(iii) Real time response for closed loop testing.
(iv) Simulation of HVDC & FACTS devices.
(v) Powerful processing hardware.
(vi) Advanced user interface.
(vii) Advance & unique power & control system component libraries.

R. Kuffel *et al*. [7] discusses the details regarding design, excellent features & wide applications of a real time digital simulator for the study of electromagnetic transient phenomenon in power systems in real time.

11. MIPOWER: This is a widely used power system & FACTS simulation software used for analysis, design & simulation of transmission and distribution systems [34]. It is widely employed for utilities, industries, engineering colleges, technical & research institutes in India & Abroad. It is followed by following features:

(i) GUI
(ii) Power flow analysis
(iii) Short circuit calculations
(iv) Transient & Dynamic stability study
(v) Load forecasting & Economic dispatch
(vi) Relay co-ordination
(vii) Harmonic Analysis etc.

13. PSIM: It is one of the best tools used especially for power electronics. The FACTS controller circuit can be designed with fast simulation. It can interface to MATLAB/SIMULINK to access complete mathematical power of Matlab [33].

Sameer Khader *et al*. [28] present the comparative study of PSIM & Matlab/Simulink software tools for power electronics and electric drives courses. Simulation of power electronic circuits & machine is done through PSIM while simulation results are analyzed with the help of Matlab/Simulink software.

14. PSPICE: It is an analog & digital simulation software program for Microsoft Windows. It is a modified PC version of SPICE. It finds wide application in analog & digital systems.

It has analog & digital libraries which contain components such as NAND, NOR, gates, Flip-Flops, operational amplifier etc. It is a circuit analyzer employed for the analysis of non-linear DC & transient, Fourier series, linear AC & noise analysis. The latest version available is PSPICE v.10. Tao Zhao *et al*. [30] throw light on the simulation of power electronic & electric drive systems.

15. CASPOC: CASPOC simulator is used for modeling and simulation of power system, power electronics, electric drives, multilevel model & FACTS controllers [35]. It also finds application in Mechatronics. Today, in the market CASPOC is the only simulator which supports circuit animation & contains a "Freeze & Go Back" function.

O. Apeldoorn [31] shows the applications of different simulation tools such as PSPICE 6.2, CASPOC, Simplorer 3.2, Matlab/Simulink, SIMSEN etc. in different fields of engineering from economical point of view. Use of these simulation tools for simulation of power electronic devices is also discussed.

16. SIMSEN: It is digital simulation software used for the analysis of power system, adjustable speed drives & hydraulic system [39]. In 1992 Simsen was developed. The latest version available is Simsen 2.3. The main features of Simsen are:

(i) Graphical input & output, Independent of network size.
(ii) Calculation of load flow with SI & per unit outputs.
(iii) Calculation of stable initial conditions.
(iv) Analysis of harmonics, transient stability, fault & sub synchronous resonance.
(v) Simulation of power system with modular structure under transient & steady state conditions.
(vi) It enables to study the dynamic behavior of power electronics converter (such as VSI, CSI, cycloconverter etc.), electrical machines & components of power systems.
(vii) It finds applications in FACTS & HVDC.

17. SABER: Simulation software SABER is used for modeling, simulating & analyzing physical systems [40]. It has wide range applications in analog/power electronics, power system, FACTS & Mechatronics. Main features are**:**

(i) Easy to use.
(ii) Provides flexibility & reliability.
(iii) Robust design methods.
(iv) Verify the behavior of physical systems (i.e. Electrical, mechanical, hydraulic etc.)
(v) Offers a graphical IDE (integrated development environment) for generating virtual prototypes of power system networks.

V. CONCLUSION

This paper presents an overview of the user friendly and widely used simulation softwares of different types used in power systems networks with their unique features. Simulation software's discussed above can be used as a major educational tool in the teaching power systems, FACTS controllers, power electronics and electrical drive of UG and PG courses as well as in research also . The paper provides relevant information about simulation tools and may act as a potential source of information for simulation agencies, research scholars, manufacturers and electrical utilities working in the field of power systems research.

ACKNOWLEDGEMENT

The authors would like to thank the Department of Energy and Department of Electrical Engineering, Maulana Azad National Institute of Technology Bhopal (M.P.), India for providing the necessary help and support for preparing this paper. The first author would like to thank the Vindhya Institute of Technology and Science Indore for sponsoring, to carry out the research work.

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