Power Simulators – A Survey

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Abstract— **The Power Simulator also termed as Dispatcher Training Simulator (DTS) is used for imparting training in power system operation and allied areas. This paper surveys a good number of literatures on for building an efficient high speed Dispatcher Training Simulator. The purpose of this work is to review and discuss various algorithms of Dispatcher Training Simulator, methodologies to add SCADA / EMS to Dispatcher Training Simulator, assessing the transient stability of the power system, and adding Flexible AC Transmission System devices to improve the performance of the power system. It also enables the readers, the lessons learnt while using Dispatcher Training Simulator. An extensive collection of literature covering modeling of devices for Dispatcher Training Simulator and expert system applications in Dispatcher Training Simulator are also included. This review opens the path for researchers to develop a more sophisticated FAST - Dispatcher Training Simulator with all FACTS devices incorporated in the power system.**

Index Terms*— *Algorithm, DTS, FACTS, SCADA / EMS, transient stability

I. INTRODUCTION

POWER system operation requires increasingly complex decision making in order to find the right compromise between economy and security. With systems being operated closer to their physical limits, their operation is becoming more and more conditioned by fast phenomena, such as loss of synchronism, frequency drops, voltage collapses, generator tripping, and by the working of the associated protections. Operators must be ready to face these circumstances by exploring the technical limits and acquiring a deeper knowledge of the behaviour of the system, including the understanding of these limits that have become imperative in today's competitive environment. This knowledge could be applied to the operation of the system in alert or in emergency conditions, when the operator has to anticipate the risks of instability. It is worthwhile to notice that the same kind of knowledge will be required during the restoration phase after a blackout. A new generation of DTS which runs at a very high speed with all FACTS devices incorporated in the power system that is capable of running in real-time with a high level of accuracy of the full electromechanical model, including the transient as well as the long-term phenomena is to be developed.

II. MODELING OF DEVICES AND DESIGN OF ALGORITHMS FOR DTS

Modern power systems are becoming increasingly complex in operation and control due to introduction of more and more new techniques and new devices into the systems. To ensure secure and economical operation of the power systems, especially in the environment of deregulation, a DTS need to be developed. Concerning the design of a DTS, it needs all components modeling, a network topology processor, an apt algorithm with necessary load

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flow methodology and transient stability analyzer, protection modeling and modeling of FACTS devices. It is essential to know about secondary devices modeling too.

Lynch (1989) presents an overview of a DTS which is designed to provide a training capability that realistically models a power system and interacts with the user in the same way as the man/machine interface in the actual control room. The system will run on either the backup side of the dual redundant EMS computer system, or it can utilize a dedicated hardware. The display representation and the operating procedures of the simulated power system are identical to those the trainees use in the real time operation. Indeed, some of the actual control consoles may be temporarily assigned to the DTS. The purpose of this operation is that, the trainee is almost unaware that he is operating the real time Energy Management System (EMS) and not the simulator, thus providing the trained a realistic experience.

Operating a power system involves on-line control to make economical operation while avoiding disruption of service to customers (secure system). Recognizing an insecure system is difficult and the dispatcher needs assistance. Specifically, the dispatcher needs an aid which will quickly recognize when the system becomes insecure to help take corrective actions. The preliminary results on using neural networks as a dispatcher's aid for power system dynamic security assessment is well explained in volume Aggoune, 1990.

The simulation of the power system is one of the basic tasks of the DTS. It enables responses to the trainee's actions in a manner consistent with the power system operation. The literature (Fuquan Wang et. al., 1991) briefly outlines the structure of a training simulator and then concentrates on the modeling of the power system. The following models are provided to simulate the dynamics of the power system and the data acquisition: Turbine and Governor Model, Boiler Model, Generator Model, Load Model, Frequency Calculation Model, Relay Model, Voltage Regulator Model, Network Model, and Telemetry Model.

The transient state of the power system is normally out of the control capability of a dispatcher. Hence, major transients are not simulated. However system dynamic changes within a time resolution of 1 to 2 seconds for all power system models are considered in the simulation. In addition, a model editor is briefly described which allows setting up models for power system components such as generating units. In the paper, Negnevitsky and Kalam, 1993, the training of power system dispatchers with the aid of simulator, combining operational switching and system working are described. The training simulator discussed belongs to a class of programmable simulators and contains a set of training procedures dealing with the most important emergency situation that are characteristic in bulk power transmission systems. Using the same training procedures, it is possible to utilize a wide range of facilities, thus abandoning the current emergency practices. The scenarios for training procedures are built on the principles which form the basis of computer-assisted learning systems, consisting of a logical sequence of separate programs. The training is carried out in a dialogue mode with a computer.

Electricite De France has been using a DTS since 1988. It is 'a full scope and stand-alone simulator which reproduces either the national or a regional control centre. The animation is based on a long term dynamic program for normal condition and on a simplified in line transient stability program for short circuit conditions, clearly explained in paper Macrez, 1994. Algebraic equations are solved with the full jacobian matrix method and differential equations with implicit trapezoidal method. That gives a large range of validity especially during the times of voltage collapse. All automata and protections are represented. Short circuit elimination is done in real time. It has a sufficient level of realism for training but the pedagogic aspect needs improvement.

At the end of 1993, the first DTS of the Hungarian electric power industry (Demjen et. al., 1994) began operation in the regional dispatcher centre of the North Hungarian Electricity Distribution Company. The simulator performs discrete, event-driven simulation of the network, the protection arrangements and the telemetry system. Its main purpose is to help the dispatchers to cope with complicated, rarely occurring disturbances in the electrical network. In the paper (Demjen et. al., 1994), an integrated DTS for use in a regional electricity distribution centre, a continuation of EDF Training Simulator, during a training session the trainee uses the same type of workstation as in the online system. The instructor's man-machine interface is implemented in DEC Windows using the colour graphics terminal of a VAX station 3100.

The simulation of the operating environment of the New York Power Pool (NYPP) within the DTS facility at the New York State Electric and Gas Corporation (NYSEG) is described in paper (Wang et. al. 1994). The NYSEG control centre uses real-time data received from the NYPP control centre to control its internal generation. In addition, the NYSEG dispatchers work very closely with the NYPP dispatchers. The exact emulation of the Generation Control functions of the NYPP Energy Management System, and the associated data exchange with the NYSEG Electronic Control System, contribute greatly to the high degree of realism achieved in the NYSEG DTS facility. The accuracy of the power system simulation in the DTS has been validated against actual power system disturbances recorded at NYSEG.

To gain knowledge and skill in operative control of power systems and interconnected power system is a complicated one, which demands solving a wide circle of scientific, technical, technological, legal and organizational tasks. The installation of an additional specialized display will facilitate the operating staff to conduct a dialog with SCADA and with the teaching system and to get necessary regime information. In the article Rabinovich et. al. (1995), the programme complex CASCADE which accomplishes functions of the training and advising system for conducting the normal, heavy and after emergency conditions is presented. The training part of the complex consists of a regime trainer for powers system dispatcher connected to an operative commutation trainer. In the same way, the training part of complex CASCADE allows to embrace by training, practically all operating staff of power systems and network enterprises.

Today's power systems have become so complex that it is not easy for the system dispatcher to realistically predict the results of outages. The situation is compounded whenever the power grid is not in its "normal" configuration due to maintenance switching or equipment failure. It has been felt that the DTS is an excellent tool that can be used to teach the dispatcher how to react under these conditions. In Subramanian et. al. (1995), the authors present an on-line implementation of the DTS which allows the user to initialize the DTS to an EMS disturbance using data that was captured at the time of disturbance and place the DTS in a playback mode and go back to specific times in the scenario. The former feature allows the analyst to investigate EMS disturbances and then train the various dispatchers to be able to recognize such disturbances and to recover from them when they occur. The latter feature allows the instructor with the trainee to review and re-experience the desired portions of the scenario. These two features will help the EMS operational staff understand their power system better and help their dispatchers in dealing with operational problems associated with the proper running of the system.

The DTS has become an important tool for Metropolitan Edison Company (Met-Ed). As new sophisticated functions are being added to Energy Management Systems, the need for dispatchers to get trained in using them in an environment similar to the on-line is also continuously growing. Met-Ed purchased its DTS as a part of the present full graphics Energy Management System. Met-Ed put in considerable effort in preparing its network model to meet the DTS training objectives and tune the unit model parameters to achieve realistic simulation responses. The first formal DTS training session began in January, 1994. The paper (Kambale and Mackauer 1996) presents the real-life use of the DTS and benefits realized from the use of the DTS. Though most of the utilities today have the DTS functionality, this DTS functionality is not being widely used. The paper also promises that the training experience presented in it will encourage the other utilities to start using the DTS as part of their regular training.

The uses of the DTS at PECO Energy are well explained in Reference (Fletcher and Coleman 1998). The primary applications of the simulator are discussed from a user's point of view rather than the technical details that describe its internal workings. Topics addressed are dispatcher training, engineering studies, Root Cause Analysis investigations (why undesirable things happened) and the use of the DTS as a public relations and confidence building tool. A discussion of the DTS training environment and general training philosophy is included along with a step by step progression through the development of a typical training exercise. It is very much essential to have a detailed discussion of the "Lessons Learned". Here such a discussion along with the recommendations for changes in the implementation of the DTS is also presented.

A fast load flow algorithm considering the effect of frequency deviations on loads and generator outputs is presented in the article (Yan Ping, 1998).The model was developed and applied to a DTS in People's Republic of China in order to meet the real time requirements of DTS, new solution techniques have been suggested to handle non-symmetric nature of the load flow Jacobian matrices resulting from the presence of the frequency deviation forms. The suggested methods reduce the memory requirement and provide faster solution.

A new generation of dispatcher training simulator called "FAST - DTS" (Sebastien Gissinger et. al., 2000) was developed with a capability of running in real-time with a high level of accuracy of the full electromechanical model, including the transient as well as the long-term phenomena. In the scenario building procedure, the instructor is no longer obliged to validate the scenario by means of numerous time-consuming offline transient stability calculations. During the training session, the simulation remains accurate and the protection system is correctly activated even if the operator deviates from the operating conditions anticipated by the instructor. In essence, the simulation is driven only by the modeling of the physics of the process and by the actions of the operator. This article analyzes the modeling and describes the algorithmic breakthroughs and the use of parallel processing. The first industrial version of the FAST-DTS (running a 400 node, 80 generator power system), with its advanced instructor and operator stations, is described and illustrated with various training scenarios. Principles used for the configuration and the compatibility with EUROSTAG (reference software dedicated to the dynamic simulation of power systems in the field of transient and long-term stability) and further developments are also discussed in detail in this paper.

The research works on Yunnan Dispatcher Training Simulator (YNDTS) is well described in paper (Yang et. al. 2003). It covers the characteristics of OPEN-2000 support platform; the hardware configuration and software architecture; the database subsystem; the man machine interface subsystem; simulation models and algorithms of YNDTS. The hardware structure and software architecture of YNDTS and the relationship between DTS and online EMS are also introduced. The models and algorithms used for power network simulation subsystem are discussed respectively. The simulation results for a number of practical cases verified the validity of the mathematical models and computational algorithms proposed in this paper, and the demand of real-time simulation was satisfied.

The design rationale and basic workings of a low-cost, easy-to- use, real-time power system simulator developed to support investigations into human interface design for a hydro power plant is well explained in paper (Memisevic et. al. 2004). The power system simulator is based on the three important components: models of power system components, a data repository, and human interface. Here Dynamic Data Exchange allows simulator components to communicate with each other within the simulator. The simulator module construction is done by combining the commercial softwares like MATLAB/Simulink, ActiveX Control, VB and Excel. An important advantage of this approach is that further components of the simulator can now be developed independently.

As a first step in developing a more sophisticated FAST – DTS, the authors of this review paper have developed an algorithm that runs with a larger step width. The article (Jovitha Jerome et. al., 2008) presents the analysis of a newly developed high-speed algorithm for a DTS. This was developed and applied to a DTS. In order to meet the real time requirements of DTS, new found methodology have been suggested to reduce the computation time. An efficient Network Topology Processor and apt component models were interfaced with this algorithm. This algorithm has been implemented in a DTS-Power System Simulation Module and tested for all the possible cases. It was found that this algorithm is guaranteed up to a step width of 0.5 second.

The simulation of observable power system dynamics realistically represents an actual power system for training. A numerically stable algorithm that can accommodate larger time step width will be an ideal choice for DTS, but it should also have smaller time step width to capture short term dynamics. Hence, an algorithm has been developed, for simulation of long-term dynamics at a 'larger time step width', in order to decrease the total simulation time while the simulation is made to run for a 24 hour system load curve and also to capture the short term dynamics with a 'small time step width'. To the knowledge of the authors' of this paper the approach used in this algorithm has not been used elsewhere. Keerthivasan et. al., 2009, presents the modeling and simulation of a variable step size algorithm for a DTS. Long-term dynamics of a power system gives an observable system response, which can be used to train system operators. Short-term dynamics gives the transient stability of the system. A combined simulation of short term and long term phenomena in power systems requires solution of a large non linear stiff set of differential-algebraic equations. An efficient Network Topology Processor and apt component models were interfaced with this algorithm. This algorithm has been implemented in a DTS - Power System Simulation Module and tested for all the following possible cases like, Bus fault application and removal, Line opening and closing, AVR set point change, Load rejection and recovery, Reactor switching, and Capacitor switching.

Modeling of equipment plays a vital role in designing a DTS. All power system components models like Turbine, Governor and Exciter model, Boiler model, Generator model, Load model, Relay model, Network model, Water system model and all secondary devices are to be developed and interfaced with the algorithm. The existing need for training dispatchers in the operation of power systems where it involves managing large water systems, problem formulation and implementation of water system modeling for DTS are presented in the paper (Rajagopal et. al. 1993). The model periodically calculates the water system flows, storage values and currently available hydro generation capacities. The model, controllable by the simulator provides the simulated telemetry of water system data to the control centre functions in the DTS. The result is validated on a large water system and the benefits of water system modeling are discussed well in this paper. To simulate secondary devices realistically in the DTS, it is important to develop a user-friendly tool to customize the secondary device models. A new approach to customize the simulation of secondary devices in DTS is presented in paper,Pan Zhelong et. al. (2002). A kind of script language is designed to define the device models, which are interpreted by an inner driver program. Meanwhile, the introduction of component models, which describe the common parts of different secondary devices, facilitates user's work. It also provides some solutions to the problem of the data management and simulation speed, therefore users can define secondary devices flexibly and control the process of power flow calculation and fault calculation by themselves. It has been applied to several practical Chinese DTS systems.

III. TRANSIENT STABILITY ANALYSIS IN A DTS

Stability of the power system is given the utmost importance everywhere. Therefore dynamic security assessment is very essential. The benefits of incorporating transient stability analysis into the DTS environment are well documented in the literatures, EPRI Report, 1984, Zhang and Bose, 1989. Transmission systems are constrained by transient stability and voltage restrictions. There is a need to provide DTS instructors (or dispatchers) with tools to obtain the transient stability analysis information relevant to existing power system conditions.

Dispatcher training in the principles and behavior of the system with respect to transient stability effects may result in giving immense benefit in interpreting heuristic constraints and handling unforeseen situations. Some new thoughts and experience gained in the area of implementing a transient stability function integrated with a DTS is shared by the authors in (Subramanian Vadari, 1991). The approach is consistent with existing DTS functions and is a step towards implementing these functions in an online Energy Management System.

III. IMPLEMENTATION OF SCADA / EMS IN DTS

Although the DTS is used primarily for dispatcher training, it may also be used for dispatcher evaluations, engineering studies, power system model evaluation, and off-line testing of energy management system functions and operating procedures. The DTS training will not only provide the dispatcher experience with man-machine interfaces, but will also provide the dynamic response when they observe it on the on-line system. Testing the performance of SCADA/EMS and application programs is one of them. But this function has not received enough attention. Early dispatching automation systems only included SCADA function. The dispatcher had to make dispatch decision by experience. This SCADA system can't satisfy the needs for the secure and economic operation, especially the needs for electric power market reformation. Therefore, some advanced functions of Energy Management Systems (EMS), including DTS, were introduced into dispatch centres. With the help of the EMS/DTS, dispatchers can carry out analysis for secure and economical operation and make decision through computer. This greatly improves decision making.

Today power systems have become so complex that SCADA/EMS has to be more powerful to fit into this situation. So getting a platform to test the performance of SCADA/ EMS is very important. The advanced DTS has same data, same display and same progam with SCADA/ EMS. Once the knowledge of using it is gained, the advanced DTS system can be a very good testing platform. In Li Quaing et. al., 1994, first, the jobs that DTS can do on testing system performance and application programs is analyzed. Then the methodology of using load forecast function and events function to finish testing work is described. At last some DTS test plans are designed to test some of the important features of SCADA/EMS.

Resent status of dispatch automation systems in China is introduced and the requirement for integrated EMS/DTS is discussed. The advantages of the integration of EMS/DTS are analyzed. Immense benefit can be obtained by developing an integrated EMS/DTS system. EMS/DTS functions for district power system application are investigated and introduced in paper (Zhang et. al., 2000). An application of the LINUX based EMS/DTS to Yulin power system is reported and is used to show the advantage of an open system. Future development of integrated EMS/DTS systems in China is also discussed in the same paper. In order to reduce investment, Henan Electric Power Dispatching and Communication Center in China established a set of Henan Dispatcher Training Simulator (HNDTS) base on its existing SCADA/EMS. The general configuration and structure of HNDTS are introduced. The integration method and techniques are proposed in the paper (Bin Hua et. al., 2004). Graph data integration is also discussed with emphasis. Both advantages and disadvantages of integration are also analyzed.

V. DESIGN OF DTS INCORPORATING FACTS DEVICES

Power electronic equipment, named Flexible AC Transmission Systems (FACTS), has been applied on some networks for the control of node voltages and rapid control of power flows on lines or along corridors. The use of FACTS devices increases the electric power system flexibility under variable operating conditions. With increased power transfer, transient and dynamic stability gains increasing importance for secure operation of power systems. FACTS devices with a suitable control strategy have the potential to significantly improve the transient stability margin. This allows increased utilization of existing network closer to its thermal loading capacity, and thus avoiding the need to construct new transmission lines. These opportunities arise through the ability of FACTS controllers to control the interrelated parameters that govern the operation of transmission systems including series impedance, shunt impedance, current, voltage, phase angle and the damping of oscillations at various frequencies below the rated frequency.

The Static Var Compensator (SVC) has proved its superiority among all the voltage stability enhancement measures available. Studies have shown that an SVC, which is properly placed, can also improve the transmission capacity. In the paper (Ning Zhu et, al., 1995), the authors have developed different SVC models for power system dynamics (short-term and long-term) as well as static analysis. With these SVC models imbedded in the DTS and associated transient stability simulation, the results obtained by analytical methods, such as the optimal location for installing an SVC as well as the control parameter settings, can be tested, evaluated and tuned under 'real time' conditions. This kind of implementation could provide valuable assistance for system planning and operation. Various tests have been conducted under different operating conditions using different SVC models to evaluate the influence of major parameter settings.

The paper (K. Keerthivasan et. al., 2005) presents modeling and interfacing techniques of SVC and Thyristor Controlled Series Capacitor (TCSC) for real time long term simulation. The proposed models are shown to be effective both for maintaining the voltage at load bus and real power flow through a typically selected line. The effectiveness of the controls is demonstrated for a standard nine bus System. The salient feature of this work is that this has been implemented in the DTS algorithm and found to be more effective. Modeling and interfacing techniques of Unified Power Flow Controller (UPFC) for real time long term dynamic simulation in a DTS is well explained in the paper Jovitha Jerome et. al., 2008. The proposed models are shown to be effective both for maintaining the voltage at a specified load bus and real and reactive power flow through a typically selected line. Finally, the paper presents the effectiveness of the controls for Anderson and Fouad nine bus System.

VI. EXPERIENCES WITH DTS

Power system operations in the 1990's pose new challenges for dispatcher training. Re-establishing service after a large scale disturbance is more complicated because networks are increasingly interconnected and heavily loaded. Maintaining the relative stability of an increasingly tightly coupled power system has also become more complex. Operating errors now can have far-reaching effects from both system stability and economic perspectives. Effective training for dispatchers and operators has become particularly critical because of their crucial decision-making role in operating the system safely and economically (James Smith, et. al., 1985). System-specific training for power system operators and dispatchers requires a clearly defined and structured training program. The program should have specific, stated objectives. The strategies and procedures put into place must work towards achieving those objectives. The training will be enhanced with a sophisticated training environment in which an operator is trained on a simulated system. This system should have the same look and feel as the real-time system, from both the user interface and system response perspectives. The DTS is an effective tool to help meet these training challenges, particularly in areas such as voltage control, stability, and system restoration training.

This paper (Bucciero et. al., 1991) is one of a series presented on behalf of the System Operations Subcommittee with the intent of focusing industry attention on current problems faced by electric utilities in the operation of the bulk power system. The five short-note reports presented draw attention to the problem areas being experienced by utilities in effective utilization of DTSs as part of the overall dispatcher training programs. Each report focuses on a different aspect of dispatcher training and utilization of power system simulation in the training curriculum. The first report addresses the justification of a training simulator and focuses on the reasons a utility should incorporate the use of a simulator in the dispatchers' training program. The second report identifies the issues associated with simulation modelling of the real power system versus generic power system modelling. The third report describes the problems experienced with usage of a simulator for power system restoration drills. The fourth report develops a set of criteria for establishing an adequate training staff to support training using a power system simulation tool. The final report explains the challenges in establishing a facility that is suitable for dispatcher training. Each of these reports is descriptive of real experiences and is intended to highlight the issues that must be addressed by the utilities in establishing a dispatcher training program and by the industry in developing the tools needed to train dispatchers effectively using power system simulation techniques. These reports contain representative lessons the industry has learned concerning the use of a DTS.

Power system operations are becoming increasingly complicated and critical. There is a need to provide more directed power system operation training than that provided by on-the-job experience. Although the primary purpose of a DTS facility is to train dispatchers and operators, the benefits derived from it as a tool in the development of programs and displays, and modeling and software errors in the real time system are appreciable. The experiences of New York Power Pool have shown the DTS to be an effective tool in the training of power system operators and dispatchers, particularly in areas such as voltage control, stability, and system restoration. In the paper (Miller et. al., 1993), the authors share some thoughts and experiences gained in the area of operator training using a simulator. Detailed descriptions have been provided regarding the simulator capabilities, training objectives, and training environment.

Several key policies are essential to the System Operator Training Program at Virginia Power (Bushnell, 1990). These policies are Training Responsibility; Performance-based Training and Multi-media approach. Each System Operator is responsible for successfully completing the training modules and on-the-job training (OJT)/qualification requirements. Each System Operator must work closely with the Shift Supervisor and the training staff to establish a training program schedule. The System Operator is then responsible for completing that program through available classroom instruction, self-study, DTS time, OJT, and other assigned training activities. The Training Program focuses on training which is specific to the System Operator's job performance requirements. As part of the training design an analysis of the System Operator job tasks and training needs was conducted. The training modules in the program have been carefully designed to address the skills and knowledge the System Operator needs. An on-going review and modification of each module is done to keep the training program current. Any training that is irrelevant to the job should be avoided. The training program uses a multimedia training approach to improve interest and increase learning retention. This includes self-study, classroom, field visits, videotapes, OJT, and simulator sessions.

The training departments need more tools to help them in the process of training the operators. In addition, they also need more help in evaluating the training session (Subramanian Vadari, 1995). This creates an iterative process, whereby the instructors can evaluate the feedback and modify the training program appropriately to cover any holes identified, or identify the weaknesses of each trainee and help them perform better. The DTS has already been recognized throughout the industry as one of the best tools to perform operator training. The authors have recognized that the actual philosophy of operator training will vary from utility to utility and will always be subjective in nature. However one common factor in most training programs is the need to collect objective data which can be used to analyze trainee/training effectiveness and present this information in the form of a report. In this paper, the authors are presenting a design and the results of a prototype implementation which will go a long way towards helping the instructor gather relevant data to evaluate the behavior of a power system during a training session. The training philosophy of a particular utility (Virginia Power) has been presented and the tool has been set up for it. The utilization of standard tools and methodologies in the design of this tool help in the ease of integration and usefulness of its outputs.

VII. CONCLUSION

Many tools exist for modeling the power system. One of the most dynamic and realistic of them is the DTS. Its value is best illustrated by creating simulated emergency conditions that provide dispatchers an opportunity to gain experience and confidence in the handling of these situations. There is a need to provide more directed power system operation training than that provided by on-the-job experience. In this paper an overall review about DTS, modeling of power system components for DTS, design of algorithms for DTS, assessing the transient stability of the DTS system, integration of existing SCADA/EMS with DTS system, modeling and incorporation of FACTS devices with DTS, and experiences using the DTS are presented.

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