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Incorporation of FACTS Controllers in Newton Raphson Load Flow for Power Flow Operation, Control and Planning: A Comprehensive Survey

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Abstract- **This paper presents a comprehensive survey of incorporation of FACTS controller such as SVC, TCSC, SSSC, STATCOM, UPFC, and IPFC devices in Newton-Raphson load flow (NRFL) for power flow control. The purpose of this paper is to present a comprehensive survey of various FACTS controllers are incorporated in load flow analysis for different point of view such as optimal power flow control, planning and operations of large-scale power system networks. Authors strongly believe that this survey article will be very much useful to the researchers for finding out the relevant references in the field of optimal power flow control of FACTS Controllers in multi-machine power systems.**

Index Terms:- Flexible A.C. Transmission system (FACTS), FACTS controllers, TCSC, SVC, SSSC, STATCOM, UPFC, IPFC, Newton-Raphson Load Flow algorithms (NRFL), load flow analysis, optimal power flow (OPF) control.

I.INTRODUCTION

THE power flow equations are non-linear algebraic equations and for which explicit solutions are not possible. These equations can be solved by iterative techniques. Historically, the first algorithm for power flow problem, employing the Gauss-Siedel method, using Ybus was reported by Ward and Hale in 1956. The Gauss-Siedel method has minimum storage requirement but has slower convergence, and in some studies fails to converge. Even to this day this method is still used when the system size is not very large. In 1961, Van-Ness and Griffins Suggested Newton's using Gaussian elimination that has the advantage of superior convergence characteristics. In 1963, Sato and Tinny introduced the concepts of optimally ordered elimination for the solution of large, sparse systems and showed such methods to be very efficient. Later in 1967, Tinney and Hart showed that by the use of optimally ordered Gaussian elimination and special programming techniques both the storage requirement and computing speed are drastically reduced by Newton's method. For systems having 200 buses or more this method is inevitably used. Newton-Raphson method with quadratic convergence characteristics has become popular for general purpose power flow study for most electric utilities.

In 1963, Brown et al. develop a method which employed the system bus impedance matrix Zbus for power flow solution. This method of power flow solution has excellent convergence characteristics, is not sensitive to initial values of the voltage profile, and can process negative impedance (series compensation of lines). However, this suffers from the disadvantage that the bus impedance matrix Zbus is a full matrix and requires very large computer memory. This barrier was overcome by applying diakoptics. However, this barrier has how become insignificant as the present day computers have very large storage capacity.

In 1972, B. Stott suggested approximations in Newton-Raphson method by decoupling MW-frequency and MVAR-voltage loops in the power system. A simplified version of decoupled method known as the fast decoupled method, with faster convergence characteristics, was suggested by B. Stott and O. Alsac in 1974. Subsequently, more work on the fast decoupled method, for faster convergence, was reported.

Load flow or power flow analysis is the determination of current, voltage, active power and reactive volt-amperes at various points in a power system operating under normal steady-state or static conditions. Load flow studies are made to plan the best operation and control of the existing system as well as to plan the future expansion. The prior information serves to minimize the system losses and to provide a check on the system stability.

There are several methods proposed in literatures for load flow analysis with incorporated FACTS controllers in multi-machine power systems from different operating conditions viewpoint. There are three methods such as a Gauss Sidel method, Newton Raphson Methods, and Fast Decouple Methods for load flow analysis with incorporated FACTS controllers from different operating conditions in multi-machine power systems for optimal power flow control. The Newton Raphson Methods have been proposed in literatures includes for Series FACTS controllers [1]-[6], Shunt FACTS controllers [7]-[11], Series-Shunt FACTS Controllers [12]-[41].

This paper is organized as follows: Section II presents the review of various FACTS controllers incorporated with Newton-Raphson load flow in multi-machine power systems for different point of view. Section III presents the summary of the paper. Section IV presents the conclusions of the paper.

II. CLASSIFICATION OF FACTS CONTROLLERS

A. Series FACTS Controllers

Reference [1], the optimal power flow (OPF) model has been developed and analyzed with Thyristor Controlled Series Compensator (TCSC) for practical power networks using Newton’s optimization technique. The minimization of total system real power losses is an objective with controlling the power flow of specified transmission lines. The proposed model has considered the optimal settings generators, transformers and TCSC devices. The optimal transmission losses and corresponding generation schedules with optimal TCSC setting parameters for different case studies have also been reported in literature. The proposed model converges very fast and independent of initial conditions. The proposed algorithm can he applied to larger systems and do not suffer with computational difficulties.

Reference [2], has been suggested to develop a steady-state mathematical model of the new generation of power electronic-based plant components presently emerging as a result of the newly developed concept of FACTS, namely TCSC. The modeling is carried out in the phase domain considering the TCSC physical structure. A poly phase power flow program based on Newton Algorithm is developed in order to implement the proposed model in literature. Analysis of the TCSC performance is carried out in both balanced and unbalanced power network operating conditions. This kind of analysis will allow quantifying the many economical and technical benefits this technology promises, as well as examining the applicability and functional specifications of the controller.

G. R. Kumar et al. [3], has been introduced the problem of reactive power compensation is viewed from two aspects: load compensation and voltage support. Voltage support is generally required to reduce voltage fluctuation at a given terminal of a transmission line. In this literature the OPF model has been developed and analyzed with TCSC and Static var Compensator (SVC) for practical power networks using Newton’s optimization technique. The optimal transmission losses and corresponding generation schedules with optimal TCSC and SVC setting parameters for different case studies have also been reported in literature. The performance of the proposed algorithm has been reported with single and multiple TCSC and SVC devices with contingency analysis and do not suffer with Computational difficulties in the literatures.

In [4], the steady state modeling of Static Synchronous Compensator (STATCOM) and TCSC for power flow studies has been presented. STATCOM is modeled as a controllable voltage source in series with impedance and firing angle model for TCSC used to control active power flow of the line to which TCSC is installed. Proposed model for TCSC takes firing angle as state variable in power formulation. To validate the effectiveness of the proposed models of Newton Raphson Method Algorithm was implemented to solve power flow equations presence of STATCOM and TCSC.

Xiao-Ping Zhang, et al. [5], has been suggested the static synchronous series compensator (SSSC) is one of the recently developed FACTS controllers. The SSSC coupled with a transformer is connected in series with a transmission line. This literature describes a multi control functional model of the SSSC for power flow analysis, which can be used for steady state control of one of the following parameters: 1) the active power flow on the transmission line; 2) the reactive power flow on the transmission line; 3) the voltage at the bus; and 4) the impedance (precisely reactance) of the transmission line. Furthermore, the proposed model can also take into account the voltage and current constraints of the SSSC device. The detailed implementation of such a multi-control functional model in Newton power flow algorithm is presented in literature. A special consideration of the initialization of the variables of the SSSC in power flow analysis is also proposed.

R. Jalayer et al. [6], the load flow problems have always been an important issue in power system analysis and require proper modeling of system components is reported. In this regard FACTS controllers are modern devices that their modeling specially the series type is a challenging topic. This literature describes a three-phase model for Distributed Static Series Compensator (DSSC) based on extending the SSSC model in Newton power flow algorithms. To extend the SSSC model the following two differences must be considered; three completely independent phases and the existence of several modules in a DSSC system.

B. Shunt FACTS Controllers

Ambriz-Perez, et al. [7], has been addressed the advanced load flow models for the SVC. The proposed models are incorporated into existing load flow **(**LF**)** and OPF Newton Algorithms. Unlike SVC models available in open literature, the new models depart from the generator representation of the SVC and are based instead on the variable shunt susceptance concept. In particular, a SVC model which uses the firing angle as the state variable provides key information for cases when the load flow solution is used to initialize other power system applications such as a harmonic analysis. The SVC state variables are combined with the nodal voltage magnitudes and angles of the network in a single frame- of-reference for Unified, iterative solution through Newton methods. Both algorithms, the LF and the OPF exhibit very strong convergence characteristics, regardless of network size and the number of controllable devices.

Reference [8], the steady-state modeling of SVC and TCSC for power flow studies has been presented in literature. Firing angle model for SVC was proposed to control the voltage at which it is connected. In same manner firing angle model for TCSC is used to control active power flow of the line to which TCSC is installed. The proposed models take firing angle as state variable in power flow formulation. To validate the effectiveness of the proposed models Newton-Raphson method algorithm was develop to solve power flow equations in presence of SVC and TCSC has been presented in literature.

In [9], has been suggested the two proposed models of the STATCOM both models suitable for three-phase power flow studies using the Newton-Raphson in both frame -of-references: polar and rectangular co-ordinates. In both cases, the STATCOM is taken to be a voltage source converter (VSC) and its associated shunt-connected transformer .The ensuing equivalent model allows for a direct voltage regulation and/or for injection of active power at the DC side of the converter. Also these models do not compromise the quadratic convergence characteristics of the Newton-Raphson method algorithm.

Reference [10], in recent years, energy, environment, deregulation of power utilities has delayed the construction of both generation facilities and new transmission lines. These problems have necessitated a change in traditional concepts and practices of power systems. There are emerging technologies available, which can help electric companies to deal with above problems. One of such technologies is FACTS. Among the converter based FACTS devices such as STATCOM and Unified Power Flow Controller (UPFC) are the popular FACTS devices. Considering the practical application of the STATCOM and UPFC in power systems, it is of importance and interest to investigate the benefits as well as model these devices for power system steady state operation. We have performed the power flow study of a five bus study system without any FACTS devices and further analyzed it with the converter based FACTS controllers. Programming of the power flow studies stated above is implemented with MATLAB.

In [11], has been introduced an efficient harmonic-oriented method based on parallel processing and the limit cycle method to compute the periodic, steady-state solution of large scale electric systems. The time domain numeric solution is based on Newton methods and the Poinare map to accelerate the convergence to the limit cycle. Furthermore, the implementation of parallel processing using MPI programming makes possible to speed up more the computations in the time domain. A three-phase version of the IEEE 118-node system is used to locate the limit cycle and study the transient response during a single-phase fault including a DVR-STATCOM in literature. This approach allows the implementation of harmonic and power quality analyses, which help to understand the real impact of the operation of FACTS controllers on the power network.

C. Series-Shunt FACTS Controllers

Reference [12], a new and comprehensive load flow model for the UPFC is has been presented. The UPFC model is incorporated into an existing FACTS Newton-Raphson load flow algorithm has been proposed in this literature. Critical comparisons are made against existing UPFC models, which show the newly developed model to be far more flexible and efficient, are concluded in this literature. It can be set to control active and reactive powers and voltage magnitude simultaneously. Unlike existing UPFC models, it can be set to control one or more of these parameters in any combination or to control none of them. Limits checking and an effective control co-ordination between controlling devices are incorporated in the enhanced load flow program. The algorithm exhibits quadratic or near-quadratic convergence characteristics, regardless of the size of the network and the number of FACTS devices.

In [13], has been showed the issue of UPFC modeling within the context of OPF solutions. The nonlinear optimization problem is solved by newton’s method leading to highly robust iterative solutions even for cases of large scale power networks, where hundreds of variables are to be optimized is presented in literature. It is presented the literature that networks modified to include several UPFCs are solved with equal reliability. The UPFC model itself is very flexible; it allows the control of active and reactive powers and voltage magnitude simultaneously. It can also be set to control one or more of these parameters in any combination or to control none of them. Considerable progress has been achieved in UPFC modeling intended for conventional load flow studies but this is the first time that the more complex issue of UPFC modeling intended for OPF solutions has been addressed in literature.

Reference [14], has been addressed the voltage source model of UPFC is incorporated in NRFL algorithm in order to investigate the control of power flow. Normally there are two ways of solving the load flow equations with UPFC. The sequential method and the simultaneous method: In sequential method the equations of UPFC are separated from the system power balance equations. Both the set of equations are solved separately and sequentially. In simultaneous method all the equations are combined in to one set of non-linear algebraic equations. A jacobian matrix is then formed which is non symmetric in nature. The simultaneous method is has been proposed for solution of non-linear algebraic equations in literature.

Reference [15], has been presented a new and comprehensive load flow model for the Unified Power Flow Controller (UPFC). The proposed model is incorporated into an existing NRFL algorithm. Unlike existing UPFC models available in open literature, it can he set to control active and reactive powers and voltage magnitude in any combination or to control none of them. A set of analytical equations has been derived to provide good UPFC initial conditions. Hence, the algorithm exhibits quadratic or near quadratic convergence characteristics. Suitable guidelines are suggested for an effective control coordination of two or more UPFCs operating in series or parallel arrangements.

Reference [16], has been introduced a generalized and improved modeling of the UPFC for NR power flow studies for power flow control. In this proposed model the sparse techniques are applied in the formulation and calculation of Jacobian matrix. While numerous studies concerning the utilization of these FACTS controllers including WFC have been carried out so far but they are not free from complex mathematical modeling and are not generalized for any FACTS devices. The proposed model can be easily extended to any FACTS devices with minor modification in the jacobian matrix of the power flow algorithm. This proposed model can be applied to larger systems and do not suffer with computational and mathematical difficulties.

Reference [17], has been presented a power-flow modeling of a UPFC increases the complexities of the computer program codes for a newton–raphson load-flow (NRLF) analysis. This is due to the fact that modifications of the existing codes are needed for computing power injections, and the elements of the jacobian matrix to take into account the contributions of the series and shunt voltage sources of the UPFC. Additionally, new codes for computing the UPFC real-power injection terms as well as the associated Jacobian matrix need to be developed. To reduce this complexity of programming codes, in this literature, an indirect yet exact UPFC model is proposed in literature. In the proposed model, an existing power system installed with UPFC is transformed into an augmented equivalent network without any UPFC. Due to the absence of any UPFC, the augmented network can easily be solved by reusing the existing NRLF computer codes to obtain the solution of the original network containing UPFC(s). As a result, substantial reduction in the complexities of the computer program codes takes place. Additionally, this proposed model in literature can also account for various practical device limit constraints of the UPFC device.

A.M. Vural, and M. Tumay et.al., [18], has been presented an improved steady state mathematical model for UPFC, which is necessary for the analysis of the steady state operation of this device embedded in a power system. The model is based on the concept of injected powers in which the operational losses can be taken into account. The model is quite suitable in load flow studies, since it accepts employing conventional techniques such as newton-raphson method and even commercial software. The effects of UPFC location on different power system parameters are entirely investigated in literature.

Reference [19], has been presented a deep investigation on the model of the UPFC, which is the most vigorous component of FACTS. The modeling of the UPFC for power flow, voltage, angle and impedance controls is presented in literature. The control modes include power flow, voltage, angle and impedance control functions. The similarities and differences between some of the control modes and those of existing traditional transformers and series compensation devices are also discussed in literature. The control modes are incorporated into a newton-raphson power flow algorithm is presented in literature.

Reference [20], has been presented an A.C Transmission system power flow can be controlled by injecting a compensating voltage in series with the line. TCSC are utilized as a conventional means for the purpose while UPFC is the latest converter based devices employing fast power electronic equipments. In this literature utilizes the steady state model of TCSC and a UPFC for series voltage compensation, and evaluating their range of power flow control for simple network. The models are incorporated into the existing Newton-Raphson load flow algorithm. The iterative equations of the Newton-Raphson load flow algorithm are modified by the device parameters and the combined set of power flow equations and UPFC or the TCSC control equations are solved for convergence of the formula. MATLAB codes are utilized for the implementation of the two devices in the NRFL algorithm in literature.

References [21], has been showed a mathematical model for eleven new UPFC series control modes. These include direct voltage injection, bus voltage regulation, line impedance compensation and phase angle regulation. Detailed implementation of the advanced UPFC model with twelve control modes (the basic active and reactive power flow control mode and the eleven new UPFC control modes) in power flow analysis is presented in literature.

Reference [22], has been presented a technique in the time domain for the fast periodic steady-state solution of systems with UPFCs incorporating three strategies for the practical representation of the UPFC commutation process. The computation of the periodic steady-state solution of power systems with UPFCs including the proposed UPFC control strategies is efficiently obtained by extrapolation to the limit cycle using a Newton method based on a numerical-differentiation procedure. The periodic steady-state solution is validated against the solution obtained with the electromagnetic transient program PSCAD/EMTDC and against an implementation with the power system block set of SIMULINK is presented in literature.

C.Angeles-Camacho, and C. R. Fuerte-Esquivel, et al. [23], has been suggested a phase coordinate steady-state model of the UPFC suitable for power flow control in unbalanced transmission networks. The UPFC power flow equations are integrated into an existing NR power flow program to assess its active and reactive power control performance is presented in literature.

Reference [24], the application of a global control based on the combination of the voltage, active and reactive power to investigate and fully understand the control capabilities and the impact of the UPFC in power flow regulation is presented in literature. These proposed models are presented in literature and analyzed in details. This literature results prove that the application of UPFC in electric power system is intended for the control of power flow, improvement of stability, voltage profile management, power factor correction, and loss minimization.

Reference [25], has been suggested a method to calculate the load flow of power system in which UPFCs are embedded. First the load flow equations of power system including the UPFCs are derived and then the algorithm is developed based on the NRLF technique. The method inherits the basic properties of the NRLF approach. Numerical computation using the proposed method in literature on standard testing programs indicates that this algorithm is reliable and efficient.

In [26], the aim of this literature is to demonstrate the superiority of using multiple UPFCs to regulate the desired power flows through any two areas in a power network and to provide the best voltage profile in the system as well as to minimize the system transmission losses by applying the proposed ANN based direct control algorithm. A complete UPFC mathematical model using power injection concept is derived and a simple way of the adaptation of the derived model in a general Newton-Raphson power flow program is also presented in literature. The basic operating principles and the control characteristics of a UPFC in steady state power flow control are fully investigated in literature.

In [27], in recent years, energy, environment, and deregulation of power utilities have delayed the construction of both generation facilities and new transmission lines is presented in literature. These problems have necessitated a change in traditional concepts and practices of power systems. There are emerging technologies available, which can help electric companies to deal with above problems. One of such technologies is FACTS. Among the converter based FACTS devices such as STATCOM and UPFC are the popular FACTS devices. Considering the practical application of the STATCOM and UPFC in power systems, it is of importance and interest to investigate the benefits as well as model these devices for power system steady state operation. In this literature performed the power flow study of a five bus study system without any FACTS devices and further analyzed it with the converter based FACTS controllers. Programming of the power flow studies stated above is implemented with MATLAB is presented in literatures.

In [28], has been suggested the UPFC steady-state modeling for the implementation of the device in the Newton-Raphson load flow algorithm. Two models, deriving from the known Voltage Source Model (VSM), are presented and analyzed in detail in literature. One is a Power Injection Model (PIM) and the other one is the new Shunt Admittance Model (SAM). Each one of these models represents a more robust and feasible alternative to the VSM because it bypasses the difficulties arising from the VSM, maintaining its advantages, though. Different simulations are presented in the literature to test and compare the models: Newton's quadratic convergence of the load flow algorithm is guaranteed by implementing the PIM and the SAM, with high convergence speeds also showed in this literature.

C.R. Fuerte-Esquivel, and E Acha et al. [29], has been addressed the issue of controllable branch models suitable for assessing the steady state response of FACTS devices on a network wide basis. Generalized nodal admittance models are presented for Series Compensators, Phase Shifters, and Inter phase Power Controllers and Unified Power Flow Controllers. A NRFL program has been developed in literature, which includes comprehensive control facilities and yet exhibits very strong convergence characteristics.

In [30], a system with a UPFC, maximum power transfer capability is often achieved when the UPFC is operated at its rated capacity and conventional voltage and line-flow set point regulation is no longer possible. This literature uses injected voltage sources to directly model a UPFC and impose the rating limits in a NRFL algorithm. A dispatch strategy is proposed for a UPFC operating at rated capacity in which the power circulation between the shunt and series converters is used as the parameter to optimize the power transfer.

In [31], the complexities of computer program codes for NRLF analysis are usually enhanced during power flow modeling of an interline power flow controller (IPFC) is presented in literature. This is due to the fact that the contributions of the series converters of the IPFC are needed to be accounted for while computing bus power injections and jacobian matrix elements. Also, the IPFC real power injection term along with its associated jacobian matrix call for new codes to be written. In this literature an advanced IPFC model is proposed to address this issue, where in an existing power system installed with IPFC(s) is transformed into an augmented equivalent network without any IPFC. To obtain the solution of the original network containing IPFC(s), the augmented network can easily be solved by reusing the existing NRLF codes, as this network is now devoid of any IPFC. Consequently, the complexities of the computer program codes are reduced substantially. Various practical device limit constraints of the IPFC can also be taken into account by the proposed model.

Reference [32], due to their ability to provide reactive power support and control active power flow, voltage-sourced-converter (VSC)-based flexible ac transmission system controllers can be used to improve the power transfer capability of congested transmission lines. A converter-based controller structure has the inherent feature to be used to provide shunt or series compensations. This inherent feature is utilized in the convertible static compensator installed at the New York Power Authority's Marcy substation, which can operate in different configurations of shunt and series compensations. Moreover, each configuration can be operated in different control modes. This literature presents a novel approach to model converter-based transmission controllers for load-flow calculations. The paper focuses on modeling converter-based controllers when two or more VSCs are coupled to a dc link such as a UPFC, IPFC, and a generalized unified power-flow controller (GUPFC). This approach also allows efficient implementation of various VSC operating limits, where one or more VSCs are loaded to their rated capacity. A computer program incorporating this approach is developed to illustrate the maximum dispatch ability of UPFC and IPFC in a large power system is presented in literature.

In [33], provides comprehensive development procedures and final forms of mathematical models of UPFC for steady-state, transient stability and eigen-values studies.

Reference [34], deals with optimal power flow control in electric power systems by use of a UPFC. Models suitable for incorporation in power flow programs are developed and analyzed. The application of UPFC for optimal power flow control is demonstrated through numerical examples. It is shown that a UPFC has the capability of regulating the power flow and minimizing the power losses simultaneously. An algorithm is proposed for determining the optimum size of UPFC for power flow applications. The performance of UPFC is compared with that of a phase shifting transformer (PST). In [35], the modeling of FACTS devices for power flow studies and the role of that modeling in the study of FACTS devices for power flow control are discussed. FACTS devices are solid state converters that have the capability of control of various electrical parameters in transmission circuits. A number of power flow study programs were developed in order to model various types of FACTS devices. Three main generic types of FACTS devices are suggested and the integration of those devices into power flow studies, studies relating to wheeling, and interchange power flow control are illustrated. In [36], introduces a hybrid flow controller (HFC) as a new member of FACTS controllers for steady-state and power-flow control of power transmission lines. HFC is a hybrid compensator (i.e., provides series and/or shunt compensation). Structurally, an HFC unit is composed of a mechanically switched phase-shifting transformer, a mechanically switched shunt capacitor, and multi module, series-connected, thyristor-switched capacitors and inductors. This paper describes the steady-state operation, single-phase equivalent circuit, power-flow model, and - and - characteristics of the HFC. This paper highlights the steady-state technical features of the HFC for power-flow control of a study system and also provides a quantitative comparison of the HFC, UPFC, and PST.

In [37], the UPFC integrates properties of both shunt and series compensations, and can effectively alter power system parameters in a way that increases power transfer capability and stabilizes system. The presents an approximate model for power flow studies that takes into consideration modeling of lossless UPFC-embedded transmission lines including the effect of line charging susceptance. The approximate model is then simplified to a dc load flow model that takes into account the modeling of the UPFC. The equations derived are applied to an optimal power flow of a small test system, where the results obtained by approximate load flow method are compared to those of dc load flow method.

In [38], presents a Newton-type current injection model of the UPFC for studying the effect of the UPFC on the low-frequency oscillations. Since the proposed model is a Newton-type one, it is conceptually simple and gives fast convergence characteristics. The model is applied to an inter-area power oscillation damping regulator design of a sample two-area power system. The damping achievable by the UPFC equipped with damping regulator is investigated in both frequency and time domains using the proposed model. The case study results in this paper show that the proposed model is efficient for studying the effects of the UPFC on the inter-area oscillations.

Reference [39], Due to their ability to provide reactive power support and control active power flow, VSC-based flexible ac transmission system controllers can be used to improve the power transfer capability of congested transmission lines. A converter-based controller structure has the inherent feature to be used to provide shunt or series compensations. This inherent feature is utilized in the convertible static compensator installed at the New York Power Authority’s Marcy substation, which can operate in 11 configurations of shunt and series compensations. Moreover, each configuration can be operated in different control modes. The presents a novel approach to model converter-based transmission controllers for load-flow calculations. The work focuses on modeling converter-based controllers when two or more VSCs are coupled to a dc link (e.g., UPFC, IPFC, and a GUPFC). This approach also allows efficient implementation of various VSC operating limits, where one or more VSCs are loaded to their rated capacity. A computer program incorporating this approach is developed to illustrate the maximum dispatch ability of UPFC and IPFC in a large power system.

In [40], presents a formulation of the OPF problem with an explicit modeling of SVC and UPFC devices. The optimization problem is solved by using Sequential Quadratic Programming, where two convergence criteria and four different methods are studied to solve the quadratic sub problems. The proposed model is integrated in an object-oriented based decision support platform for competitive power markets. Validation of the method and practical applications to real longitudinal systems are discussed, where FACTS location and a UPFC-based interconnection are described. Results show the impact of SVC and UPFC FACTS technologies in the physical and economic behavior of a real system.

Reference [41], describes a novel power injection model (PIM) of IPFC for power flow analysis. The proposed model, the impedance of the series coupling transformer and the line charging susceptance are all included. In this situation, it is proved that the original structure and symmetry of the admittance matrix can still be kept, and thus, the jacobian matrix and keep the block-diagonal properties, and sparsity technique can be applied. The IPFC state variables are adjusted simultaneously with the network state variables in order to achieve the specified control targets. Furthermore, the model can take into account the practical constraints of IPFC in Newton power flow.

III. SUMMARY OF PAPER

The following tables give summary of the paper as:

Type of FACTS Controllers	**Total No. of Literatures out of 41 Literatures**	**% of Literatures out of 41 Literatures**
Series FACTS Controllers	6	14.63
Shunt FACTS Controllers	6	14.63
Series-Shunt FACTS Controllers	29	70.73

From above tables it is concluded that the 15.00% of total literatures are reviews related with series FACTS controllers, 15.00% of total literatures are reviews related with shunt FACTS controllers, and the 70.00% of total literatures are reviews related with series-shunt FACTS controllers.

Finally it is concluded that the maximum research work carryout from series-shunt FACTS controllers incorporated in Newton-Raphson load flow of power system from different point of view such as optimal power flow control, planning and operations of large power system networks.

IV. CONCLUSIONS

This paper has been presented a review of an OPF model incorporating various types of FACTS controllers using Newton-Raphson algorithm. This model is capable of solving power networks of any size and converges with minimum number of iterations and independent of initial conditions. The Newton power flow algorithm has been proposed in literatures will be a very useful tool to understand and explore the operation and control capabilities of the FACTS controllers in practical power systems. The Newton power flow programme code with the modeling the FACTS controllers is a useful tool for power system planning, operational planning, and operation/control of large-scale power systems. The strong multiline control capability of the FACTS Controllers with controlling bus voltage or/and multiline power flows will he likely to play an important role in solving many of the potential problems facing electric utilities in the deregulated electricity market environment.

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REFERENCES

[1] Abdel-Moamen, M.A. Narayana Prasad Padhy, " Power Flow Control and Transmission Loss Minimization Model with TCSC for Practical Power Networks", Power Engineering Society General Meeting, 2003, IEEE, Vol.2, 13-17 July 2003, pp 880-884.

[2] Venegas T., Fuerte-Esquivel, C.R. "Steady-State Modelling Of Thyrister Controlled Series Compensator For Phase Domain Load Flow Analysis Of Electric Network", Electric Utility Deregulation and Restructuring and Power Technologies, 2000. Proceedings. DRPT 2000. International Conference, 4-7 April 2000 Page(s):191 – 196.

[3] Kumar, G.R.; Rao, R.K.; Ram, S.S.T., Power Flow Control and Transmission Loss Minimization model with TCSC and SVC for Improving System Stability and Security**"** Industrial and Information Systems, 2008. ICIIS 2008. IEEE Region 10 and the Third international Conference on 8-10 Dec. 2008 Page(s):1 – 5.

[4] M.O. Hassan, S. J. Cheng , and Z. A. Zakaria, " Steady-state Modeling of Static Synchronous Compensator and Thyristor Controlled Series Compensator for Power Flow Analysis," Information Technology Journal, Vol. 8, Issue 3, 2009, pp. 347-353.

[5] Xiao-Ping Zhang, 'Advanced Modeling of the Multi control Functional Static Synchronous Series Compensator (SSSC) in Newton Power Flow", Power Systems, IEEE Transactions on Volume 18, Issue 4, Nov. 2003 Page(s):1410 - 1416 .

[6] Jalayer R., Mokhtari, H. "A Simple Three-phase Model for Distributed Static Series Compensator (DSSC) in Newton Power Flow "Power and Energy Engineering Conference, 2009. APPEEC 2009. Asia-Pacific 27-31 March 2009 Page(s):1 – 5.

[7] Ambriz-Perez, H.; Acha, E.; Fuerte-Esquivel, C.R., "Advanced SVC Models for Newton-Raphson Load Flow and Newton Optimal Power Flow Studies" Power Systems, IEEE Transactions on Volume 15, Issue 1, Feb. 2000 Page(s):129-136.

[8] M.O. Hassan, S. J. Cheng , and Z. A. Zakaria, " Steady-state Modeling of SVC and TCSC for Power Flow Analysis," Proceedings of International Multi Conference of Engineering and Computer Scientists 2009, Vol. II,IMECS2009,March 18-20, 2009, Hong Kong.

[9] C. Angeles-Camacho, E. Acha, and E. Barrios-Martínez, "Three-phase STATCOM Models for Large-scale Newton-Raphson Power Flow Studies," Power Tech., 20076, IEEE Lausanne, 1-5 July, 2007, pp. 1250-1255.

[10] Sahoo, Ashwin Kumar, Dash S.S., and Thyagarajan, T., **"**Modeling of STATCOM and UPFC for power system steady state operation and control" Information and Communication Technology in Electrical Sciences (ICTES 2007), 2007. ICTES. IET-UK International Conference on
20-22 Dec. 2007 Page(s):458 – 463.

[11] Norberto Garcia, "Parallel Harmonic-Oriented Method for Large-Scale Electric Systems Based on MPI Programming and the Limit Cycle Method," Power Tech., 2005, IEEE Russia, 27-30 June, 2005, pp. 1-6.

[12] C.R. Fuerte-Esquivel, and E Archa, "Unified power flow controller: a critical comparison, of Newton-Raphson UPFC algorithms in power flow studies," IEE Pro,.-Gener. Transm. Distrib., Vol. 144, No. 5, September 1997.

[13] H. Am briz-Perez E.Acha C.R. Fuerte-Esquivel A.De la Torre, "Incorporation of a UPFC model in an Optimal Power Flow Using Newton's method," *IEE Proc.-Gener. Transm. Distrib., Vol. 145, No. 3, May 1998.*

[14] Samina Elyas Mubeen, R. K. Nema , and Gayatri Agnihotri, "Power Flow Control with UPFC in Power Transmission System," Proceedings of World Academy of Science, Engineering and Technology, Volume 30, July 2008, pp. 955-959.

[15] C. R. Foerte-Esquivel, E. Acha, and H. Amhriz-Pbrez, "**A** Comprehensive Newton-Raphson UPFC Model for the Quadratic Power Flow Solution of Practical Power Networks," IEEE Trans on Power Systems**,** Vol.15, NO. 1, February 2000, pp.102-109.

[16] Abdel Moamen M. A, and Narayana Prasad Padhy, "Newton-Raphson UPFC Model for Power Flow Solution of Practical Power Networks with Sparse Techniques," 2004 IEEE International Conference on Electric Utility Deregulation, Restructuring and Power Technologies (DRPT2004) April 2004 Hong Kong.

[17] Suman Bhowmick, Biswarup Das, *Senior Member,* and Narendra Kumar, "An Indirect UPFC Model to Enhance Reusability of Newton Power-Flow Codes," IEEE Trans on Power Delivery, Vol. 23, No. 4, October 2008, pp.2079-2088.

[18] A.M. Vural, *Student Member, IEEE,* and M. Tumay, "Steady State Analysis of Unified Power Flow Controller: Mathematical Modeling and Simulation Studies," Paper accepted for presentation at 2003 IEEE Bologna Power Tech Conference, June 23-26**,** Bologna, Italy.

[19] Wenjin Dai, and Zhihong Liu, "Study on Modeling of Unified Power Flow Controller," Proceedings of the IEEE International Conference on Automation and Logistics, August 18 - 21, 2007, Jinan, China.

[20] Samina E. Mubeen, R. K. Nema, and Gayatri Agnihotri, "Comparison of Power flow control: TCSC versus UPFC," Power System Technology & IEEE Power India Conference 2008, POWERCON-2008, 12-15 October 2008, pp. 1-5.

[21] Xiao-Ping Zhang, and Keith R Godfrey, "Advanced Unified Power Flow Controller Model for Power System Steady State Control," 2004 IEEE International Conference on Electric Utility Deregulation, Restructuring and Power Technologies (DRPT2004) April 2004 Hong Kong.

[22] Juan Segundo and Aurelio Medina, Senior Member, "Periodic Steady-State Solution of Electric Systems Including UPFCs by Extrapolation to the Limit Cycle," IEEE Trans on Power Delivery, Vol. 23, No. 3, JULY 2008, pp. 1506-1512.

[23] C.Angeles-Camacho,and C. R. Fuerte-Esquivel, "A Three Phase UPFC model for Power Flow Control in Unbalanced Transmission Networks," Cigre Papers, 2001.

[24] Belkacem Mahdad1, Tarek Bouktir2 ,and Kamel Srairi, "The Impact of Unified Power Flow Controller in Power Flow Regulation," IEEE MELECON 2006, May 16-19, Benalmádena (Málaga), Spain, pp. 1015-1019.

[25] Fang Wanliang, and H.W.Ngan, "Extension of Newton Raphson Load Flow Techniques to Cover Multi Unified Power Flow Controllers," Proceedings of the 4th International Conference on Advances in Power

System Control, Operation and Management, APSCOM-97, Hong Kong, November 1997.

[26] K. L. Lo, T. T. Ma, J. Trecat, and M. Crappe “A Novel Power Flow Control Concept Using ANN Based Multiple UPFCs Scheme,” Energy and Management and Power Delivery, 1998, Proc. Of EMPD-98, International Conference, Vol. 2, 3-5 March, 1998, pp. 570-575.

[27] Ashwin Kumar Sahoo, S.S. Dash, and T. Thyagarajan, “Modeling of STATCOM and UPFC for Power System Steady State Operation and Control, “IET-UK International Conference on Information and Communication Technology in Electrical Sciences (ICTES 2007),Dr. M.G.R. University, Chennai, Tamil Nadu, India. Dec. 20-22, 2007. pp.458-463.

[28] A. L’Abbate, M. Trovato, C. Becker, and E. Handschin, “Advanced Steady-State Models of UPFC for Power System Studies,” Power Engineering Society Summer Meeting, 2002, IEEE, Vol. 1, 25 July, 2002, pp. 449-454.

[29] CR Fuerte-Esquivel ,and E Acha, “A Newton-Type Algorithm for the Control of Power Flow in Electrical Power Networks,” IEEE Transactions on Power Systems, Vol. 12, No. 4, November 1997,pp. 1474-1480.

[30] Xuan Wei, Joe H. Chow, B. Fardanesh, and Abdel-Aty Edris,, “A Dispatch Strategy for a Unified Power-Flow Controller to Maximize Voltage-Stability-Limited Power Transfer,” IEEE Trans. on Power Delivery, Vol. 20, No. 3, July 2005, pp.2022-2029.

[31] Suman Bhowmick, Biswarup Das, and Narendra Kumar, “An Advanced IPFC Model to Reuse Newton Power Flow Codes,” IEEE Trans. on Power Systems, Vol. 24, No. 2, May 2009, pp.525-532.

[32] Xia Jiang, Xinghao Fang, Joe H. Chow, Abdel-Aty Edris, Edvina Uzunovic, Michael Parisi, and Liana Hopkins, “A Novel Approach for Modeling Voltage-Sourced Converter-Based FACTS Controllers,” IEEE Trans. on Power Delivery, Vol. 23, No. 4, October 2008, pp.2591-2598.

[33] Nabavi-Niaki, M. R. Iravani, “Steady-State and Dynamic Models of Unified Power Flow Controller (UPFC) for Power System Studies," IEEE trans. on Power Systems, Vol.11, No.4, Nov. 1996, pp.1937-1943.

[34] M. Noroozian, L. Angquist, M. Ghandhari, and G. Andersson, "Use of UPFC for Optimal Power Flow Control," IEEE Trans. on Power Delivery, Vol. 12, No. 4, Oct. 1997.

[35] Douglas J. Gotham, G. T. Heydt, “Power Flow Control and Power Flow Studies for Systems with FACTS devices," IEEE trans. on Power Systems, Vol.13, No. 3, July 1997, pp.60-65.

[36] S. Ali Nabavi Niaki,, Reza Iravani, *a*nd Mojtaba Noroozian, “Power-Flow Model and Steady-State Analysis of the Hybrid Flow Controller,” IEEE Trans. On Power Delivery, Vol.23, No.4, October 2008, pp. 2330-2338.

[37] Muwaffaq I. Alomoush, “Derivation of UPFC DC Load Flow Model with Examples of its Use in Restructured Power Systems,” IEEE trans. on Power Systems, Vol.18, No. 3, August 2003, pp.1173-1180

[38] Kwang M. Son, and Robert H. Lasseter, **“**A Newton-Type Current Injection Model of UPFC for Studying Low-Frequency Oscillations,” IEEE Trans. on Power Delivery, Vol. 19, No.2, April 2004,pp.694-701.

[39] Xia Jiang, Xinghao Fang, Joe H. Chow, Abdel-Aty Edris, Edvina Uzunovic, Michael Parisi, and Liana Hopkins, “A Novel Approach for Modeling Voltage-Sourced Converter-Based FACTS Controllers,” IEEE trans. on Power Delivery, Vol. 23, No. 4, October 2008, pp. 2591-2598.

[40] Rodrigo Palma-Behnke, Luis S. Vargas, Juan R. Pérez, Jaime D. Núñez, and Rigoberto A. Torres, “OPF With SVC and UPFC Modeling for Longitudinal Systems,” IEEE Trans. on Power Systems, Vol. 19, No.4, November 2004 , pp. 1742-1753.

[41] Yankui Zhang, Yan Zhang, and Chen Chen, “A Novel Power Injection Model of IPFC for Power Flow Analysis Inclusive of Practical Constraints,” IEEE Trans. on Power Systems, Vol. 21, No. 4, November 2006, pp. 1550-1556.

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