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A Study on Enhancement of Loadability of Large-Scale Emerging Power Systems by Using FACTS Controllers

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Abstract-**This study presents comprehensive review of various methods/techniques for incorporation of differential algebraic equations (DAE) model of FACTS controllers and different type of loads such as a static, dynamic, and composite load model in large-scale emerging power systems for enhancement of loadability of power system networks. It also reviews various current techniques/methods for incorporation differential algebraic equations (DAE) model of FACTS controllers and different type of loads such as static, dynamic, and composite load model in emerging power system networks through all over world. 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 incorporation of FACTS controllers in power system environments for enhancement of loadability of power system environments.**

Index Terms-Flexible AC Transmission Systems (FACTS), FACTS Controllers, SVC, TCSC, SSSC, STATCOM, UPFC, IPFC, Static ZIP Loads, Dynamic Loads, Composite Loads, Loadability of Power Systems, Contingencies of power systems.

I.INTRODUCTION

THE DEREGULATED power system has a basic challenge to provide network capable of delivering contracted power from any supplies to any consumers over a large geographical area with continuously varying pattern of contractual agreements. Thus, the problem of power system security has obtained much attention in the deregulated power industry. In the present pace of power system restructuring, transmission systems are required to provide increased transfer capability and to accommodate much wider range of possible generation patterns. Environmental right-of-way and cost problems are major hurdles for power transmission network expansion. Hence, there is an interest in better utilization of the existing power system capabilities.

To utilize the network potential to its full capacity in the restructured electricity environment, it has become important to determine the loadability of power system, so that the available transfer capability can be posted on the website for its optimum commercial use. These studies can suggest the better distribution of its generation sources, future requirement of installation of new transmission lines, and the option of installation of power flow control equipment to enhance the existing transmission transfer capability. Flexible AC transmission system (FACTS) controllers have large potential ability to make power systems to operate in a flexible, secure, and economical way.

The load modeling has been studied since a long time ago in order to improve the accuracy of power system analysis [1]. The load model is classified into two types; 1) Static Load Model, 2) Dynamic Load Model, and 3) Composite Load Model.

The representative static load model is a polynomial-based model which is composed of constant impedance characteristics, constant current characteristics, and constant power characteristics. That static model is also known as ZIP model [1] and is often expanded to the static load model with frequency characteristics using a proportion coefficient.

The improvement in the system loadability using genetic algorithm (GAs) and the cost of production were discussed in [2] and [3]. The method in [2] is applied to allocate a maximum of 50 FACTS controllers in IEEE 118-bus network. In [3], location of phase shifters were determined and restricted to a subset of 124 possible corridors. Reference [4], the allocation of thyristor controlled phase angle regulators (TCPARs) and thyristor controlled series capacitors (TCSCs) is carried out through sensitivity analysis. The method however does not maximize the system loadability.

This paper is organized as follows: Section II discusses the mathematical modeling of static and dynamic loads. Section III introduces the incorporation of FACTS controllers in power systems. Section IV introduces the shortcoming of a literature survey. Section V presents the review of various techniques/methods for placement and Coordination of FACTS controller in large-scale power systems from loadability point of view. Section VI presents the summary of the study. Section VII presents the conclusions of the study.

II.MATHMATHICAL MODEL OF STATIC ZIP, DYNAMIC, COMPOSITE, PTI EEE, AND EXPONENTIAL LOADS

This paper study the following five load models appropriate for the power system for comparative analysis.

A. *Static ZIP Load Model:*

As shown in (1) and (2), the load is decomposed into its active and reactive parts each represented by three components, namely, the constant impedance part (Z),constant current part (I), and the constant power (P) part [5]:

$$P_L = P_0\left\{a_1(V)^2 + a_2(V) + a_3\right\} \tag{1}$$

$$Q_L = Q_0\left\{a_4(V)^2 + a_5(V) + a_6\right\} \tag{2}$$

Where

$P_L, Q_L =$ active and reactive power load, respectively;

$P_0, Q_0 =$ active and reactive power load at specified bus;

$a_1, a_4 =$ constant impedance load part;

$a_2, a_5 =$ constant current load part;

$a_3, a_6 =$ constant power load part;

$a_1 + a_2 + a_3 = 1,$

$a_4 + a_5 + a_6 = 1.$

B. *Dynamic Motor Load Model:*

In this model, active and reactive parts of the load are expressed as a function of the past and present system voltages and frequencies and represented by an induction motor equivalent circuit as shown in Fig. 1 [6]:

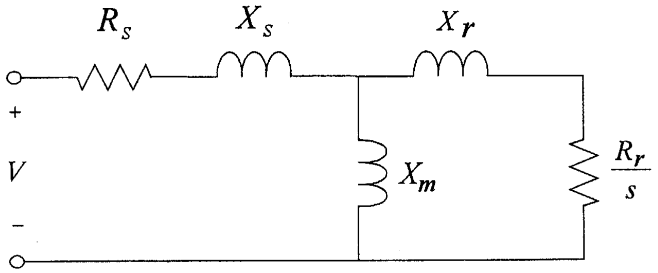

Fig. 1. Dynamic induction motor equivalent circuit.

Where

$R_s =$ *static impedance;*

$R_r =$ *rotor impedance;*

$X_m =$ *excited reactance;*

$X_s =$ *static reactance;*

$X_r =$ *rotor reactance;*

$s =$ *rotor slip.*

C. *Composite Load Model:*

This is a combination of the static and dynamic load models presented in [6] whose equivalent circuit is shown in Fig. 2.

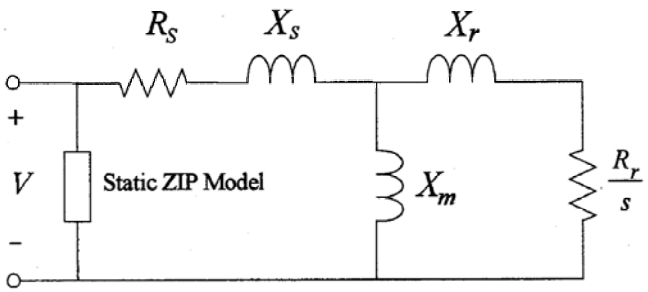

Fig. 2. Equivalent circuit of composite model.

D. *PTI IEEE Model:*

According to this model, active and reactive part of the load shall be represented by (3) and (4) which are both voltage and frequency dependent presented in [7]:

$$P_L = P_0(a_1V^{K1} + a_2V^{K2} + a_3V^{K3})(1 + a_4\Delta f) \tag{3}$$

$$Q_L = Q_0(a_5V^{K4} + a_6V^{K5} + a_7V^{K6})(1 + a_8\Delta f) \tag{4}$$

where frequency deviation $\Delta f = 60 - f'$.

E. *Exponential Model:*

As represented by (5) and (6), using an arbitrary exponential of system voltages, this load model has the characteristics of using fewer parameters and is usually used to represent mixed load [5]:

$$P_L = P_0\left(\frac{V}{V_0}\right)^{K_{PV}} \tag{5}$$

$$Q_L = Q_0\left(\frac{V}{V_0}\right)^{K_{QV}} \tag{6}$$

Where

$K_{PV} =$ voltage dependent parameter of the active power;

$K_{QV} =$ voltage dependent parameter of the reactive power;

$V =$ actual voltage;

$V_0 =$ nominal voltage.

III. DAE MODEL OF POWER SYSTEM INCORPORATED WITH FACTS CONTROLLERS AND DFFERENT TPYES OF LOADFS FOR LOADABILITY VIEWPOINT

Small signal stability studies and their related tools are typically based on the following general DAE mathematical description of the power system:

$$\dot{x} = f(x, y, \lambda, p)$$
$$0 = g(x, y, \lambda, p)$$

Where

$x \in R^n$ = Represents the system state variable, corresponding to dynamical state of generators, loads and any other time varying element in the system, such as FACTS controllers;

$y \in R^n$ = Corresponds to the algebraic variables, usually associated to the transmission system and steady-state element models, such as some generating sources and loads in the power system networks;

$\lambda \in R^n$ = Stands for a set of uncontrolled parameters that drive the system to collapse, which are typically used to represent the somewhat random change in system demand. Vector

$p \in R^n$ = Used here to represent system parameters that are directly controllable, such as shunt and series compensation levels.

Based on above equations, the operating parameters of power systems such as voltage stability may be defined, under certain assumptions, as the equilibrium point where the related system Jacobian is singular, i.e., the point $(x_0, y_0, \lambda_0, p_0)$ where

$$\left[\frac{f(x, y, \lambda, p)}{g(x, y, \lambda, p)}\right] = F(z, \lambda, p) = 0$$

And $D_z F_0$ has a zero egen-value [8]. This equilibrium is typically associated to saddle-node bifurcation point.

For a given set of controllable parameters p_0, voltage collapse studies usually concentrate on determining the collapse or bifurcation point $(x_0, y_{0,} \lambda_0)$, where λ_0 typically corresponds to the maximum loading level or loadability margin in p.u., %, MW, MVar or MVA, depending on how the load variations are defined. Based on bifurcation theory, two basic tools have been developed and applied to the computation of this collapse point, namely, direct and continuation methods [9].

Since one is mostly interested in the collapse point and its related zero eigen-values and eigenvectors, it has been presented in [10] that not all dynamical equations are of interest; precise results may be obtained if the set of equations used in the computation of the collapse point adequately represent the equilibrium equations of the full dynamical system. Control limits are of great importance in this case, as these have significant effect on the values of $(x_0, y_0, \lambda_0, p_0)$; this has been clearly illustrated for generators in [11]-[12]. In this case of FACTS controllers, this implies that adequate controller models must accurately reproduce steady-state behavior and control strategies; including all associated limits.

IV. SHORTCOMING OF A LITERATUTERE SURVEY

One of the major causes of voltage instability is the reactive power limits of the power systems. The many literatures have proposed solutions for this problem, by using suitable location of Flexible AC Transmission Systems (FACTS) and proper coordination between FACTS controllers to improve voltage stability of the power systems. Hence, improving the systems reactive power handling capacity via Flexible AC transmission System (FACTS) device is a remedy for prevention of voltage instability and hence voltage collapse.

The several literatures are proposed the different methods/techniques for placement of FACTS controllers, and coordination of FACTS controllers, one of the shortcomings of such methods is that they only consider the normal state of system. However, voltage collapses are mostly initiated by a disturbance (e.g. the outage of a line, or fault on system or generation unit, or increased in load demand). So to locate FACTS devices, consideration of contingency conditions is more important than consideration of normal state of system and some approaches are proposed to locate of FACTS devices with consideration of contingencies, too presented in the many literatures.

To increase system loadability only, exploring and exploiting the available network without considering the investment of new electrical equipments including generator, transmission line and transformer et al., a novel mathematical model is proposed. It has the objective function of maximising the system loadability while simultaneously satisfying system operating constraints including transmission line capacity limits and voltage level limits in order to implement the optimal location and parameters of given number of UPFCs.

V. INCORPORATION OF FACTS CONTROLLERS IN LARGE-SCALE POWER SYSTEMS FOR ENHANCEMENT OF LOADABILITY OF POWER SYSTEMS

The incorporation of FACTS controllers in power system networks for enhancement of loadability of power systems.

A. By Placement of FACTS Controllers in Power System Networks

1) By Series FACTS Controllers

With their ability to change the apparent impedance of a transmission line, FACTS devices may be used for active power control, as well as reactive power or voltage control. For a meshed network, an optimal location of FACTS devices allows to control its power flows [13] and thus to increase the system loadability [14], [15]. However, a limit number of devices, beyond which this loadability cannot be improved, has been observed [16].

Reference [17], proposes a new method of optimal number and location of TCSC using mixed integer non-linear programming approach in the deregulated electricity markets. Optimal number and location of TCSC controller can effectively enhance system loadability and their placement is a crucial issue due to their high cost. Since, in the competitive electricity environment more and more transactions are negotiated, which can compromise the system security. Therefore, it has become essential to determine secure transactions occurring in the new environment for better planning and management. The system loadability has been determined in a hybrid market model utilizing the secure transaction matrix.

The ongoing power system restructuring requires an opening of unused potentials of transmission system due to environmental, right-of-way and cost problems which are major hurdles for power transmission network expansion. FACTS devices can be an alternative to reduce the flows in heavily loaded lines, resulting in an increased loadability, low system loss, improved stability of the network, reduced cost of production and fulfilled contractual requirement by controlling the power flows in the network. In [18], presented the first few optimal locations of FACTS devices and then determines the best optimal location in order to reduce the production cost along with the device cost. In this literature, a method to determine the few locations of thyristor controlled series compensators(TCSC) and thyristor controlled phase angle regulators(TCPAR) in the network has been suggested based on the sensitivity of the real power flow performance index. Thereafter, the optimal location is decided based on the maximizing social benefit but minimizing the price based curtailment of pool and bilateral dispatch by ensuring minimum device cost.

Flexible Alternating Current Transmission Systems, called FACTS, got in the recent years a well-known term for higher controllability in power systems by means of power electronic devices. FACTS-devices can effectively control the load flow distribution, improve the usage of existing system installations by increasing transmission capability, compensate reactive power, improve power quality, and improve stabilities of the power network. However, the location of these devices in the system plays a significant role to achieve such benefits. In [197], presents the application of Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) techniques for finding out the optimal number, the optimal locations, and the optimal parameter settings of multiple Thyristor Controlled Series Compensator (TCSC) devices to achieve a maximum system loadability in the system with minimum installation cost of these device. The thermal limits of the lines and the voltage limits for the buses are taken as constraints during the optimization. Simulations are performed in this literature on IEEE 6-bus and IEEE14-bus power systems. The obtained results are encouraging, and show that TCSC is one of the most effective series compensation devices that can significantly increase the system loadability. Also the results indicate that both GA and PSO techniques can easily and successfully find out the optimal variables, but PSO is faster than GA from the time perspective.

2) *By Shunt FACTS Controllers*

Kumar et al. [20] proposed mixed integer linear programming approach for combined optimal location of FACTS controllers for loadability enhancement in pool and hybrid electricity markets. The system loadability in competitive environment has been calculated in [21].

In [22], the authors use standard voltage collapse analysis tools to study the effect in the maximum load margin of the location of a given SVC; an approximate SVC model is used for the computations.

Reference [23], presents a sensitivity based approach to determine optimal location of SVC for voltage security enhancement. The proposed approach of SVC placement computes sensitivity of system loading factor with respect to reactive power generation, derived from reactive power balance equation. This sensitivity factor has been termed as Bus Static Participation Factor (BSPF). The sensitivity of the most critical eigen value with respect to bus voltage magnitude has been considered as Bus Dynamic Participation Factor (BDPF). BSPF and BDPF have been combined to obtain Bus Hybrid Participation Factor (BHPF), which have been computed for the system intact case and critical contingency cases and used for selecting the optimal site for the SVC installation. The effectiveness of the proposed approach of SVC placement has been validated on a practical-75-bus Indian system with respect to enhancement of the static as well as dynamic voltage stability margins.

3) *By Series-shunt FACTS Controllers*

Reference [24], a method to determine the suitable locations of unified power flow controller, with static point of view, has been suggested, based on the sensitivity of system loading with respect to control parameters of the UPFC.

A parallel Tabu search based optimal location of UPFC and its impact on enhancement of ATC has been proposed in ref. [25].

The unified power flow controller (UPFC) is one of the most promising Flexible AC Transmission Systems (FACTS) devices for the load flow control. Simultaneous optimization of location and parameters for UPFCs is an important issue when the given number of UPFCs is applied to the power system with the purpose of increasing system loadability. In [26], presents a mathematical model about optimal location and parameters of UPFCs to maximize the system loadability subject to the transmission line capacity limits and specified voltage level. An improved computational intelligence approach: self-adaptive evolutionary programming (SAEP) is used to solve the nonlinear programming problem presented above for better accuracy. Furthermore, steady-state performance of power system can be effectively enhanced due to the optimal location and parameters of UPFCs.

In [27], a Genetic Algorithm (GA) is used for determining optimal location of UPFC in power systems. Optimal location in this paper means finding line number for UPFC location and its parameters for specified number of UPFCs. UPFC is considered as a powerful FACTS device in this ref. Unlike other FACTS devices, UPFC has a great flexibility that can control the active and reactive powers and voltage, simultaneously. The system loadability is applied as a measure of power system performance. Injection model of UPFC is used in the simulation. The concept of simulation is the load flow incorporated with UPFC. The results show that steady state performance of the power system can be effectively enhanced due to the optimal location and parameters of UPFC.

Fang and Ngan et al. [28] suggested an augmented Lagrange Multipliers approach for optimal location of UPFC in power systems to enhances the steady state performance and significantly increase the loadability of the system.

The increases in power flows and environmental constraints are forcing electricity utilities to install new equipment to enhance network operation. Some application of FACTS technologies to existing high-voltage power systems has proved the use of FACTS technology may be a cost-effective option for power delivery system enhancements. Amongst various power electronic devices, the UPFC device has captured the interest of researchers for its capability of regulating the power flow and minimizing the power losses simultaneously. Since for a cost-effective application of FACTS technology a proper selection of the number and placement of these devices is required, the scope of literature [29] is to propose a methodology, based on a genetic algorithm, able to identify the optimal number and location of UPFC devices in an assigned power system network for maximizing system capabilities, social welfare and to satisfy contractual requirements in an open market power.

In [30], presented a Genetic Algorithm (GA) is used for determining optimal location of UPFC in power systems. Optimal location in this literature means finding line number for UPFC location and its parameters for specified number of UPFCs. UPFC is considered as a powerful FACTS device in this paper. Unlike other FACTS devices, UPFC has a great flexibility that can control the active and reactive powers and voltage, simultaneously. The system loadability is applied as a measure of power system performance. Injection model of UPFC is used in the simulation. The concept of simulation is the load flow incorporated with UPFC.

In [31], to identify the optimal location of the Unified Power Flow Controller (UPFC) in electrical power systems. The proposed algorithm is based on the power injection model for UPFC incorporating Optimal Power Flow (OPF) in steady-state analysis. The problem is formulated to find the best location of UPFC in order to optimize the fuel cost function, power losses and the system loadability as objective functions while the investment on the UPFC device is minimized.

4) *By Combination of Series, Shunt, Series-Shunt FACTS Controllers*

Reference [32], presents an approach for identifying the most effective Flexible AC Transmission System (FACTS) Controllers, locations, types and ratings that increase asset utilization of power systems. The approach is a combined static/dynamic procedure based on the use of a continuation power flow, an optimal power flow and an eigen-value analysis. The application of this approach on a representative studied transmission system has resulted in an increase of the maximum stable loadability limit by 6.**7** %. Finally shows that the proposed approach is helpful in coordinating the functionality of FACTS Controllers to enhance power system dynamics. FACTS controllers are used in this proposed model such as SVC and TCSC.

In [33], presents optimum required rating of series and shunt flexible ac transmission systems controllers for EHVAC long transmission lines. This is achieved by computing optimum compensation requirement (OCR) for different loading conditions of EHVAC transmission systems. The OCR enables improvements to be made to the system loadability, total compensation requirement, line voltage profile and efficiency of power transmission. Two schemes of locating FACTS devices in long distance EHV transmission lines is discussed. In the first scheme, an UPFC of equal rating series and shunt compensator is connected on both ends of the line. In the second scheme SVC of equal rating is connected on both ends with a TCSC at the middle of the same line. For each scheme, requirement of series compensation Mvar, shunt compensation Mvar, Voltages (Vmax, Vmin), total Mvar requirement, Efficiency for surge impedance load is calculated and presented.

There are several methods for finding locations of FACTS devices such as Thyristor Control Series Compensator(TCSC),Thyristor Controlled Phase Angle Regulator(TCPAR), Static Var Compensators (SVC) and Unified Power Flow Controller (UPFC) in both vertically integrated and unbundled power systems [34]-[35] for meeting the different objectives. However, to the best of authors' knowledge, there is no paper, that suggests a simple and reliable method for determining the suitable location of the UPFC for enhancing the loadability of the power system. A unified power flow controller (UPFC) is the most effective and versatile FACTS device capable of controlling instantaneous power flow and provides dynamic control of system parameters (voltage, line impedance, and phase angle) independently or simultaneously in appropriate combinations. Using controllable components of the UPFC, the line flow scan be changed in such a way that more loading on the network can made without violating operating limits of the system. Since insecure cases often represent the most severe threats to secure system operation, it is important that the FACTS devices should enhance the system security by enhancing the system loadability along with the other control devices.

Lima et al. [36] proposed number, network location, and settings of phase shifters to maximize system loadability in a electricity market using MILP.

Kazemi et al. [37] proposed eigen vector analysis for optimizing location, sizing and control modes of SVC and TCSC in order to achieve the maximum loadability.

Reference [38], suggested to investigate the application of FACTS devices to increase the maximum loadability of the transmission lines which may be constrained by a transient stability limit. Hence, the on-line fuzzy control of the Super-conducting Magnetic Energy Storage (SMES) and the Static Synchronous Series Compensator (SSSC) are proposed. The fuzzy rule-bases are defined and explained. The validity of the suggested control strategies are confirmed by simulation tests. The simulation results show that by the use of the proposed method, the line power transfer can be increased via the improvement of the transient stability limit. Finally,the effect of the control loop time delay on the performance of the controller is presented.

The problem of finding out which positions are the most effective and how many Flexible AC Transmission System(FACTS) devices have to be installed and controlled in a deregulated environment on economic basis is a question of great significance for the Dispatcher. In [39], presents a flexible approach based in practical reasoning rules from fuzzy logic theory capable of governing multiple Static Var Compensator (SVC) and a group of Static Compensator (STATCOM) by a flexible adjustment of reactive power injected or absorbed from the network. The main purpose of the presented coordinated strategy is the improvement of system loadability of the power systems. Reactive index sensitivity coordinated with an expert rules to form a global database as a flexible tool to make an efficient decision about reactive power dispatch and to choose the size of the shunt FACTS Controllers. Simulation results show clearly the advantage of this approach to enhance the reactive power planning.

Reference [40], suggested four kinds of FACTS controllers in order to increase the loadability margin of a power system. The appropriate representation including the equations in the DC parts of these FACTS devices is incorporated in the continuation power flow (CPF) process in static voltage stability study. Based on the above observation, an effort made in this paper is to compare the merits and demerits of some FACTS devices, namely, SVC, STATCOM, TCSC and UPFC, in terms of Maximum Loading Point (MLP) in static voltage stability study. This leads to a more practical solution in terms of MLP or voltage stability margin, which may be useful for utilities to select the most beneficial FACTS devices among SVC, STATCOM, TCSC and UPFC.

A two-step procedure is proposed in [41] to locate and adjust phase shifters angles. In the first step, the theoretical system maximum loadability is found without restrictions on number and location of the control devices. In the second step, this ideal loadability is maintained while minimizing the system-wide installed phase shifter capacity. The assumption here is that every line in a system has an installed phase shifter whose setting is optimally adjusted with in the line flow limits. This is a continuous variable optimization that does not solve the optimum FACTS location problem in the integer sense.

The flexible AC transmission system (FACTS) in a power system improves the stability, reduces the losses, reduces the cost of generation and also improves the loadability of the system. In [42], the proposed work, a non-traditional optimization technique, a Genetic Algorithm (GA) is conjunction with Fuzzy logic (FL) is used to optimize the various process parameters involved in introduction of FACTS devices in a power system. The various parameters taken into consideration were the location of the device, their type, and their rated value of the devices. The simulation was performed on a 30-bus power system with various types of FACTS controllers, modeled for steady state studies. The optimization results are compared to the solution given by another search method. This comparison confirms the efficiency of the proposed method which makes it promising to solve combinorial problem of FACTS device location in a power system network.

A sensitivity based approach has been proposed to determine the placement of TCSC and UPFC for enhancing the power system loadability [43]. In [44], a Particle Swarm Optimization (PSO) technique has been addressed for optimal location of FACTS controllers such as TCSC, SVC, and UPFC considering system loadability and cost of installation.

Luna and Maldonado et al. has been addressed a new methodology is based on the evolutionary strategies algorithm known as Evolution Strategies (ES) for optimally locating FACTS controllers in a power system for maximizes the system loadability while keeping the power system operating within appropriate security limits [45].

In [46], an eigen-value analysis based approach has been proposed for find the optimal location and rating of FACTS controllers (Static Var Compensator (SVC) and Thyristor Controlled Series Controller (TCSC)) and a continuation power flow is used to evaluate the effects of SVC and TCSC devices on power system loadability. A sensitivity based approach has been proposed for placement of FACTS controllers in open power markets to reduce the flows in heavily loaded lines, resulting in an increased loadability, low system loss, improved stability of the network, reduced cost of production and fulfilled contractual requirement by controlling the power flows in the network in [47]-[48].

The authors of the current paper present in [49] a first attempt to adequately model SVCs and TCSCs for the study of voltage collapse phenomena; techniques are proposed to determine adequate design parameters, particularly location, to produce a "maximum" increment in the loadability margin. In the current paper, better models and new methodologies are proposed, especially for the TCSC, with the aim of producing optimal improvements in the loadability margin. Furthermore, the effect of SVC and TCSC sizing, i. e., compensation levels, in the loading margin, which is discussed in general for shunt and series compensation in [50], is specifically addressed in this paper.

FACTS devices, such as the Thyristor Controlled Series Compensator (TCSC) and Static Var Compensators (SVC), can help increase system load margin to improve static voltage stability. In power systems, because of the high cost and the effect value, the optimal placement for FACTS devices must be determined. In [51], investigates the use of the series device (SVC) and the parallel device (TCSC) from the point of load margin to increase voltage stability. It considers the sensitivity of load margin to the line reactance and eigenvector of the collapse. The proposed method in this literature has been carried out on the IEEE 14 Bus Test System to verify the validity and efficiency of the method. It reveals that incorporation of FACTS devices significantly enhance load margin as well as system stability.

The flexible AC transmission system (FACTS) in a power system improves the stability, reduces the losses, reduces the cost of generation and also improves the loadability of the system. In [52], the proposed work, a non-traditional optimization technique, a Genetic Algorithm (GA) is conjunction with Fuzzy logic (FL) is used to optimize the various process parameters involved in introduction of FACTS devices in a power system. The various parameters taken into consideration were the location of the device, their type, and their rated value of the devices. The simulation was performed on a 30-bus power system with various types of FACTS controllers, modeled for steady state studies. The optimization results are compared to the solution given by another search method. This comparison confirms the efficiency of the proposed method which makes it promising to solve combinorial problem of FACTS device location in a power system network.

B. *By Coordination of Multiple FACTS Controllers in power System Networks*

1) *By Series FACTS Controllers*

In [53], a new power flow control method based on a coordination of load shedding and FACTS devices is presented. Two types of FACTS devices, a Thyristor Controlled Series Capacitor (TCSC) and a Thyristor Controlled Phase Shifting Transformer (TCPST), are considered in this study.

2) *By Shunt FACTS Controllers*

In [54], study the effects of three FACTS controllers: STATCOM, SSSC and UPFC on voltage stability in power systems. Continuation power flow, with accurate model of these controllers, is used for this study. Applying saddle node bifurcation theory with the use of Power System Analysis Toolbox (PSAT), the optimal location of these controllers are determined. Using a 6-bus test system the effects of these controllers on voltage stability are examined. It is found that these controllers significantly increase the loadability margin of power systems.

3) *By Series-Shunt FACTS Controllers*

One of the major causes of voltage instability is the reactive power limit of the system. Improving the system's reactive power handling capacity via Flexible AC transmission System (FACTS) devices is a remedy for prevention of voltage instability and hence voltage collapse. In [55], the effects of two FACTS controllers, STATCOM and UPFC, on voltage stability will be studied. Continuation Power Flow (CPF), with accurate model of these controllers, is used for this study. Applying saddle node bifurcation theory with the use of Power System Analysis Toolbox (PSAT), the optimal location of these controllers is determined. The study has been carried out on the 6-bus and IEEE 14-Bus Test Systems and results are presented.

Reference [56], a method to coordinate stabilizers so as to increase the operational dynamic stability margin of power systems is proposed. This solution indirectly takes into account different operating conditions to design robust stabilizers based on local measurements. Non-linear simulation on a sample 46-machine power system, including a thyristor controlled series capacitor (TCSC) and an unified power flow controller (UPFC), is employed to explore the effectiveness of the procedure.

In [57], presented a proposal for the solution of voltage stability when a contingency has occurred, using coordinated control of Flexible AC Transmission Systems (FACTS) devices located in different areas of a power system. An analysis of the initial conditions to determine the voltage stability margins and a contingency analysis to determine the critical nodes and the voltage variations are conducted. The response is carried out by the coordination of multiple-type FACTS devices, which compensate the reactive power, improving the voltage stability margin of the critical nodes.

Reference [58], an optimal procedure for designing co-ordinated controllers of power system stabiliser and flexible ac transmission system devices is developed for achieving and enhancing small-disturbance stability in multi-machine power systems. A constrained optimization approach is applied for minimising an objective function formed from selected eigen-values of the power systems state matrix. The eigen-value–eigenvector equations associated with the selected modes form a set of equality constraints in the optimisation. There is no need forany standard eigenvalue calculation routine, and the use of sparse Jacobian matrix in the case of large system for forming the eigen-value–eigenvector equations leads to the sparsity formulation. Inequality constraints include those for imposing bounds on the controller parameters. Constraints which guarantee that the modes are distinct ones are derived and incorporated in the control coordination formulation using the property that eigenvectors associated with distinct modes are linearly independent. The robustness of the controllers is achieved very directly through extending the sets of equality constraints and inequality constraints in relation to selected eigen-values and eigenvectors associated with the state matrices of power systems with loading conditions and/or network configurations different from that of the base case. Simulation results of a multi-machine power system confirm that the procedure is effective in designing controllers that guarantee and enhance the power systems mall-disturbance stability.

4) By Combination of Series, Shunt, Series-Shunt FACTS Controllers

An eigen value analysis approach has been addressed for modeling and simulation of SVC and TCSC to study their limits on maximum loadability point in [59], [60].

In [61], presents detailed steady state models with controls of two Flexible AC Transmission System (FACTS) controllers, namely, Static Var Compensators (SVCs) and Thyristor Controlled Series Capacitors (TCSCs), to study their effect on voltage collapse phenomena in power systems. Based on results at the point of collapse, design strategies are proposed for these two controllers, so that their location, dimensions and controls can be optimally defined to increase system loadability.

The collapse points are also known as maximum loadability points; in fact, the voltage collapse problem can be restated as an optimization problem where the objective is to maximize certain system parameters typically associated to load levels [62, 63,64, 65]. Hence, voltage collapse techniques may also be used to compute the maximum power that can be transmitted through the transmission system, also known in the new competitive energy market as Total Transfer Capability or as Available Transfer Capability (ATC) [66].

In [67], presents a flexible approach based in practical reasoning rules from fuzzy logic theory capable of governing multiple Static Var Compensator (SVC) and a group of Static Compensator (STATCOM) by a flexible adjustment of reactive power injected or absorbed from the network. The main purpose of the presented coordinated strategy is the improvement of system loadability. Reactive index sensitivity coordinated with an expert rules to form a global database as a flexible tool to make an efficient decision about reactive power dispatch and to choose the size of the shunt FACTS Controllers.

Reference [68], focused on detailed steady state models with emphasize on control loops of two FACTS devices, namely, SVC and TCSC , to study their effects on voltage collapse phenomena in power systems. Based on results at the point of collapse control loops strategies which could increase system loadability or increase loadability margin to collapse point are determined.

VI. RESULTS AND DISCUSSIONS

The following tables give summary of the paper as:

5.1 By Placement of FACTS controllers in large-scale emerging power system networks

From figure 1 it is concluded that the 7 of total literatures are reviews based on series FACTS controllers, 4 of total literatures are reviews based on shunt FACTS controllers, 8 of total literatures are reviews on series-shunt FACTS controllers, and 21 of total literatures are reviews based on combination of series, shunt, series-shunt FACTS controllers for enhancement of loadability of large-scale power systems.

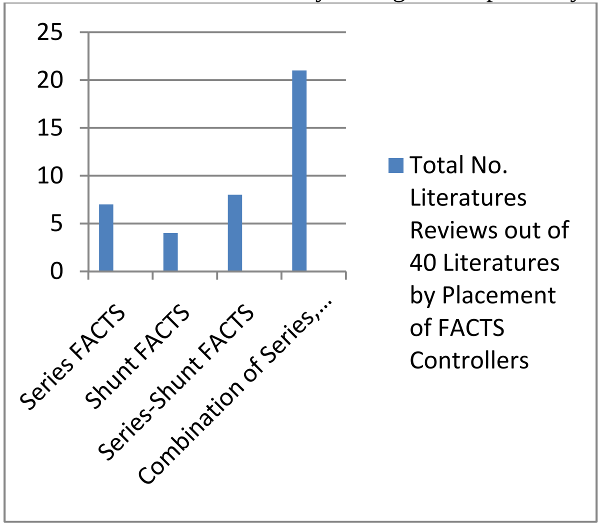

Figure 1 By placement of FACTS controllers in large-scale emerging power system networks

5.2 By Coordination of FACTS controllers in large-scale emerging power system networks

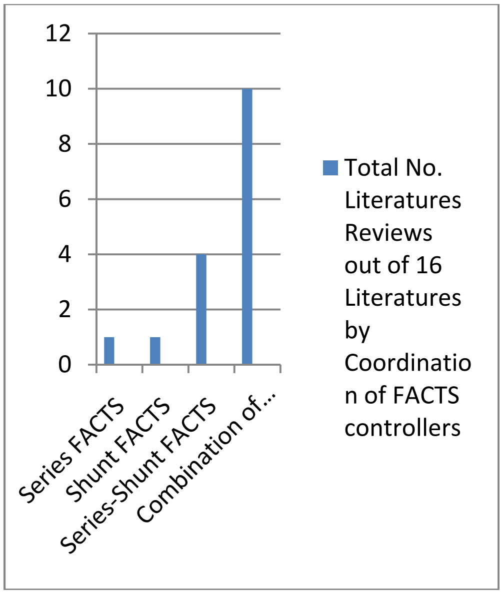

Figure 2 By coordination of FACTS controllers in large-scale emerging power system networks

From figure 2 it is concluded that the 1 of total literatures are reviews based on series FACTS controllers, 1 of total literatures are reviews based on shunt FACTS controllers, 4 of total literatures are reviews on series-shunt FACTS controllers, and 10 of total literatures are reviews based on combination of series, shunt, series-shunt FACTS controllers for enhancement of loadability of large-scale power systems.

5.3 By Placement and Coordination of FACTS controllers in large-scale emerging power system networks

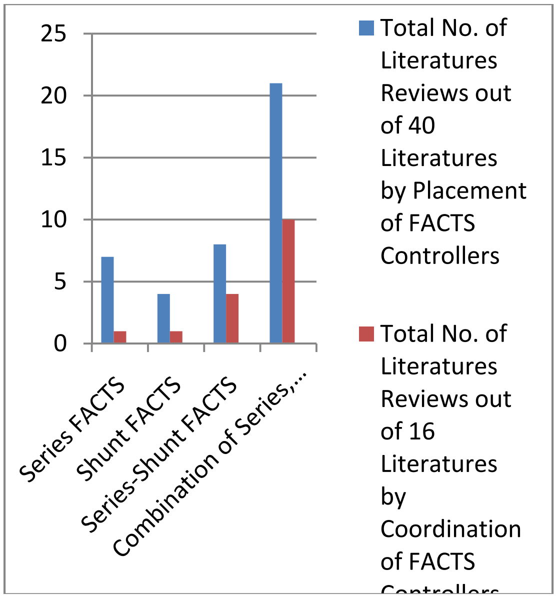

Figure 3 By placement and coordination of FACTS controllers in large-scale emerging power system networks

From figure 3 finally it is concluded that the maximum research work carryout from placement of FACTS controllers for enhancement of loadability of power systems.

6. CONCLUSIONS

This paper has also addressed a survey of several technical literature concerned with various techniques/methods for incorporation of differential algebraic equations (DAE) model of FACTS controllers and different type of loads such as a static, dynamic, and composite load model in large-scale emerging power systems for enhancement of loadability of power system networks. By using placement and coordination of multiple FACTS controllers in large-scale emerging power system networks to also show that the achieve significant improvements in operating parameters of the power systems such as small signal stability, transient stability, damping of power system oscillations, security of the power system, less active power loss, voltage profile, congestion management, quality of the power system, efficiency of power system operations, power transfer capability through the lines, dynamic performances of power systems, and the loadability of the power system network also increased.

Authors strongly believe that this survey article will be very much useful to the researchers for finding out the relevant references as well as the previous work done in the field of enhancement of loadability of power systems by using placement and coordination of FACTS Controllers in power systems. So that further research work can be carried out.

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