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UPFC FACTS Controller Based Compensation of Power System: A Survey

Aditya Mishra [1], Prof.Girraj Prasad Rathor[2],
[1]M.Tech Scholar, [2]Assistant Professor,
[1,2]Department of Electrical & Electronics Engineering,
[1,2]Technocrats Institute of Technology & Science, Bhopal (M.P), India
[1]adityamishra90980@gmail.com,

***Abstract*— Flexible ac transmission systems (FACTS) may benefit from power electronic controllers that provide better control over power flow, secure loading, as well as oscillation dampening. VAR compensation, line impedance management, and phase angle shifting may all be provided by a UPFC as one of the FACTS components. The UPFC is made up of 2 inverters, one of which is linked to the transmission line in series through a series transformer, and the other of which is connected in parallel via a parallel transformer to the transmission line. By varying the parallel inverter's injected voltage's magnitude and phase angle, the transmission line's actual as well as reactive power flows may be modulated. When used in conjunction with a series inverter, the parallel inverter's primary purpose is to provide the actual power needed by the series inverter. Reactive power may be generated or absorbed by the parallel inverter in many ways. A UPFC was used to improve the active and reactive power flow of the power systems, but most of those studies are discussed in this section.**

Keywords- low-frequency oscillation(LFO), Automatic voltage regulator (AVR), Alternating current (AC), power system stabilizers (PSS).

I. INTRODUCTION

In order to meet the rapid increase in power demand, the power system networks need to expand proportionately which is not the practical scenario due to the constraints of limited resources and environmental factors. This situation forcing most of the power systems to operate close to their stability limits. The power systems interconnected through weak tie lines give rise to poorly damped low-frequency oscillation (LFO) which lies in the frequency range of 0.1–3 Hz. If adequate damping is not provided, these LFOs keep increasing, eventually leaving the system out of synchronism. Many types of research have been carried out for years by engineers to solve the problem. The control of generator excitation employing automatic voltage regulator (AVR) provides a solution to damp out these LFOs. However, the uses of high-gain AVRs with synchronous generators with a view to maintaining constant voltage also create LFOs by decreasing rotor damping torque . Consequently, power system stabilizers (PSS) are widely used to enhance the stability of power system against LFOs. Though the PSSs are the proven tools to damp out LFOs, PSS may fail to suppress the oscillations caused by severe disturbances like three-phase fault close to the generator terminals and may affect the voltage profile. On the contrary, the application of flexible alternating current (AC) transmission systems (FACTS) has become prevalent with the advancement of power electronic devices. The capability of very fast power electronic-based & control action has made the FACTS devices a strong candidate in improving power system damping. Application of FACTS devices has shown promising results for steadystate performance improvement in power system. FACTS devices enhance the system stability by controlling the dynamic state of system parameters which include voltage, current, series and shunt impedance, phase angle and damping of LFOs [10]. Applications of FACTS devices have been reported for various control objectives including optimal power flow (OPF), voltage stability, damping inter-area LFOs. The structure of FACTS devices can be series, shunt and different formation of series and shunt controllers. The unified power flow controller (UPFC) is the combined unit which takes advantage of independent series and shunt controllers . Unified power flow controller (UPFC) is the most popular and one of the most promising second-generation FACTS devices. It has the capability of dealing with the bus voltage, the angle between the buses and line reactance which are the three most important parameters in controlling stability issue. The way UPFC works is by controlling the power transfer through transmission lines during the steady-state condition of the system. Additionally, UPFC is capable of improving transient stability, providing voltage support, reducing power loss and damping out LFOs]. UPFC performs all these tasks with its power flow controller, supplementary damping controller and a direct current (DC) voltage regulator. The success of the UPFC controller to suppress oscillations depends on the proper selection of the control parameters. In order to guarantee system stability during disturbances, it is required to maintain proper coordination between UPFC and PSSs. A great number of researches have been reported in the literature in the field of coordination among PSS and FACTS device controllers. Different artificial intelligence techniques were being employed in power system industries in order to solve many complex problems as well as optimizing the parameters of FACTS devices. Besides, the parameters of UPFC-coordinated PSS were optimized employing backtracking search algorithm, genetic algorithm, differential evolution, ant colony optimization , and particle swarm optimization in order to improve the power system stability by damping out the small signal oscillations. However, most of these techniques work in the off-line mode as these required a very longer time to get the optimized parameters for different operating conditions.

The concept of FACTS was first introduced by Hingorani in. These devices not only have the capability in controlling active and reactive power flow in an electrical network but also can redistribute power flow even under highly loaded condition that ultimately have the effect in reducing overall congestion. Hence FACTS controllers can be used to increase system loadability as situation demands. Steady state and transient stability is also improved with the help of FACTS controller. TCSC is a series connected devices used in power systems to control the reactance of a transmission line thereby controls line power flow in one way. SVC is a shunt connected device which regulates the voltage of transmission system at a selected terminal by controlling reactive injections. UPFC is a combination of a static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC) coupled via a common DC voltage link used for controlling active and reactive power flow through the lines. It also has direct impact in controlling voltage. Reactive power flow control by FACTS devices to increase transmission capacity is discussed in. Optimal placement of FACTS devices increases the power transfer limit in the system as discussed in [3–5]. Minimization of transmission loss and improvement of voltage profile with the help of FACTS controller is presented in. Linear programming (LP) optimization methodology is discussed in for the reactive power control in hybrid power system. Optimal power flow along with the power injection model of FACTS devices is the main issues of. Linear programming approach is used in for optimum reactive power dispatch. An algorithm that includes reactive power pricing concept is presented in for the minimization of active power loss as well as voltage stability improvement. An improved evolutionary programming (IEP) technique to solve the optimal reactive power dispatch (ORPD) problem is discussed in. In author has presented enhanced Genetic Algorithm for the solution of optimal power flow with both continuous and discrete control variables. FACTS devices are used in for the improvement of available transfer capacity (ATC) during normal as well as contingency situations using real-coded GA. Jerbex et al. provide an idea for the optimal allocations of FACTS devices, without considering the investment cost of FACTS device. Das et al. applied GA for the optimum value of fixed and switched shunt capacitors in minimizing energy loss and in maintaining acceptable voltage profile at load buses under different loading conditions on a radial distribution network. In GA is used for the optimal power flow solution for a six bus system. Graphical user interface (GUI) based on GA is used in for the determination of optimal positions and magnitudes of multi-type FACTS devices in large power systems in minimizing active power loss of the system. Multi-objective problem of a power system is solved by proper allocation of series and shunt FACTS controller in . Basu et al. presented DE algorithm for the minimization of generator fuel cost using FACTS devices. Verma et al. used UPFC at the suitable locations of a connected power network for congestion management. Determination of optimal position and sizing of UPFC for congestion management of transmission network is presented in. Optimal setting of UPFC devices to minimize the total operating cost is discussed in.

A. Power System Dynamic Model

The single-machine infinite-bus (SMIB) power system equipped with UPFC has been considered as shown in Fig. 1.

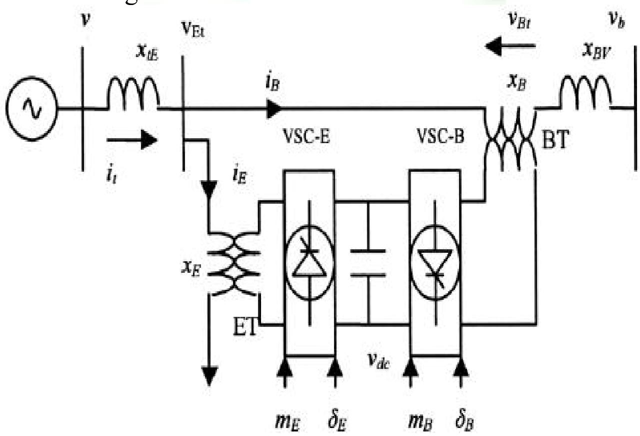

Fig. 1. SMIB system equipped with UPFC [24]

The C-UPFC is evolved conceptually from the UPFC. One returns first to the UPFC and considers the level of series voltage compcnsation rcqitired for phase-shifting or line inductive reactance compensation in the radial line. Then, one imagines the series converter and its scries transformer. which have the MVA ratings to provide for the phase shifting or the series voltage compensation, as broken into two approximate halves. Each half series converter and its associated half transformer is attached on either side of the center-node to which the shunt converter is also connected. The three Voltage-Source Converters constitute the C-UPFC. The dc terminals of the two "halved" converters are joined together to form its dc bus network with its dc capacitor. The real power rectified into the series converter on one side of the center-node. finds its exit via the dc link as the inverted power of the other series Converter. Thus, unlike the UPFC, the real ac powers of the series converters do not pass through the shunt converter. In order to emphasize this feature, the dc bus of the series converters is treated as separate from the dc bus of the shunt converter in this paper. In fact, the shunt converter functions exclusively as a STATCOM, although some of the VAR support can be provided by cheaper dielectric capacitors, which are incremented in steps by switches. The purpose of presenting the three-converter C-UPFC as an evolution of the two-converter UPFC is to show that the cost increase will be within reason. As the compensating voltage phesor of the two series converters of the C-UPFC are not necessarily collinear. fi-om Schwartz's inequality the sum of the MVAs of the two series converters of the C-UPFC will be larger than the MVA of the single converter of the CUPFC.

II LITERATURE SURVEY

Biswas, S., et al (2020),This research work presented a two criteria-based new fault detection and classification scheme is presented in this article for protecting the UPFC compensated TLs connecting wind farms. The presented, method employs the sign of the change in the magnitude of the positive sequence current at both ends of the line for fault detection and TMIs derived from the locally measured three-phase currents for fault classification.The performance of the presented method is evaluated on different faults simulated on two different test systems through EMTDC/PSCAD by varying the fault inception angle, fault location, fault resistance, UPFC This article has been accepted for inclusion in a future issue of this journal. Content is final as presented, with the exception of pagination. operational mode, and wind speed. The different possible critical faults (high resistance faults, faults causing CT saturation, and voltage/current inversion) and non fault transients (switching ON/OFF of large loads and capacitor banks) are also considered for performance evaluation. Furthermore, the performance of the presented method is validated through dSPACE DS 1103-based real-time digital simulation platform. The requirement of only current information, relatively low computational burden, easy real-time implementation, fast response time (less than a-cycle), and comparatively high fault detection (100%) and classification (99.24%) accuracies are the main advantages of the presented method compared to the existing methods**[01]**.

Rana, M. J., et. al (2019), In this research work**, t**he objective of this research work is to design and investigate the performance of PSS coordinated with UPFC-based damping controller for improving damping of LFOs of the power system in real time. For online parameter estimation of damping controller, Levenberg–Marquardt algorithm trained neural network has been employed. The presented controller performance has been tested for three different loading conditions and compared with fixed gain-based conventional controller. From the eigenvalue analysis and time domain representation of system parameters, it is seen that presented controller outperforms the conventional one in all respect. Furthermore, it is found that the time required for the LM-NN to tune the controller parameters is less than two cycle of the power system. Thus, the faster speed of computation and convergence of the presented technique demonstrate its efficacy and robustness for real time application. Additionally, the satisfactory values of selected statistical performance measures validate the effectiveness of the presented LM-NN in predicting UPFC coordinated PSS parameters. As a future extension, the presented technique will be implemented experimentally in order to reinforce the effectiveness of LM-NN in damping out LFOs in SMIB system **[02]**.

Shahriar, M. S., et al (2018), This research work investigating the real-time performance of UPFC coordinated PSS connected power system subjected to low frequency oscillations is the main objective of this work Support vector regression model estimates the parameters of PSS coordinated with UPFC in real-time fashion. The performance of presented technique is tested for three different loading conditions. In addition, the obtained results are compared with the fixed gain PSS coordinated with UPFC. From the eigenvalue analysis and time domain representation of system parameters, it is seen that presentedcontroller outperforms the conventional one in all respect. Furthermore, it is found that the time required for the SVR model to tune the controller parameters is less than two cycles of a 60 Hz power system. Thus, in terms of computational speed and accuracy, the presented model presents its efficiency as a real-time optimizer and ensures robustness in power system stability enhancement. Besides, satisfactory values of the statistical performance measures for training and testing datasets provide confidence on the presented SVR model. However, the idea presented in this research work can be further extended for tuning the PSS parameters of a multi machine power system network**[03].**

Chandwani, A., et al. (2017, March), In this research work presented, demonstrates performance of space vector modulation performance based unified power flow controller. Converters of UPFC are controlled through d-q reference frame technique. The presented UPFC is analyzed for steady as well as transient conditions due to load changes. Simulation results presented, clearly depict the effective control of active as well as reactive power in the system by presented UPFC under both steady state as well as transient conditions**[04]**.

Mishra, S. K., et al. (2016, October), In this research work a FDST based differential relaying scheme for Single circuit transmission line protection including UPFC is presented. The scheme is validated for detecting and classifying faults including wide variations of Rf, source impedance and power reversal flow of internal fault including the parameter variations of UPFC. Thus, the relaying scheme is highly selective in discriminating internal and external faults within a response time of two cycle **[05].**

Peng, F. Z., et al. (2015), In this research work a new transformer-less UPFC based on a novel configuration and control of two CMIs was presented. It has been demonstrated that the new UPFC can achieve the same controllability as the traditional UPFC. However, the traditional UPFC consisting of two back-to-back inverters requires isolation and zigzag transformers. The new UPFC consisting of two CMIs offers several advantages over the traditional UPFC: such as completely transformer-less and highly modular structure, light weight, high efficiency, high reliability, low cost, and fast dynamic response. The new transformer-less UPFC is therefore very suited for fast and distributed power flow control of wind and solar power transmission. The operating principle and performance of the transformer-less UPFC have been fully analyzed by detailed theory. A 13.8-kV/ 2-MVA prototype is setup and experimental results have been shown to demonstrate the functionality of UPFC**[07].**

Bhattacharyya, B., et al.. (2014), In this research work presents, Genetic Algorithm (GA) and Differential Evolution (DE) approach are used for the optimal allocation and setting of FACTS devices along with reactive generation of generators and transformer tap positions. Two cases are considered for the optimal location and types of FACTS devices. In the first case, TCSC as a series controller and SVC as a shunt FACTS controller is used along with the existing power system variables for obtaining economic operation of the power system. In case II, UPFC is used with the series and shunt FACTS controllers as mentioned along with the existing power system variables in minimizing active power loss and system operating cost as case I. It is observed that use of UPFC along with series and shunt FACTS controller gives better result than without UPFC. Active power loss and operating cost reduced significantly and huge economic gain are achieved with the placement of UPFC along with other FACTS controller by both the GA and DE based optimization techniques**[08]**.

III. IMPACTS OF THE INSTALLATIONS OF UPFC AND WIND FARMS ON DISTANCE RELAYS

A sample two-bus test system is modeled using PSCAD/EMTDC software for evaluating the impact of UPFC-compensated lines connecting offshore wind farms on distance relay performance. As shown in the figure, the UPFC is installed at the beginning of a 400-kV TL and the other end of the line has provision to be connected either to Source-2 or to the offshore wind farms or both. The UPFC basically consists of two VSCs namely the STATCOM and SSSC that are mutually connected through a dc-link capacitor C and are connected to the line through two coupling transformers T1 and T2, respectively. The UPFC is operated in three modes of operation.

1) STATCOM mode: In this mode, the connecting point voltage (Vref) is varied by means of injecting/absorbing the reactive power into/from the network. In this article, the Vref is set for two values (1.1 and 0.95 p.u.).

2) SSSC mode: In this mode, the variation of injecting voltage and current flow through the network is remained quadrature to operate the SSSC as capacitor or inductor. Here, Qref is set +0.8 p.u. (absorbing reactive power) and −0.8 p.u. (generating reactive power).

3) UPFC mode: In this mode, both the STATCOM and SSSC operate together. The reference powers Pref, Qref are set for two values (10 p.u., +0.7 p.u. and 10 p.u., −0.7 p.u.) keeping Vref = 1.1 p.u. During any of these operating modes, the presence of UPFC in the fault loop imposes under-reaching and over-reaching problems to distance relay.

4)

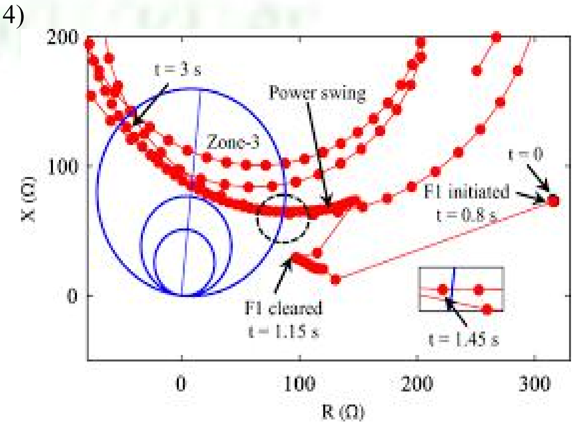

Fig. 2 Locus of the apparent impedance seen at relay R1 during the occurrence

The output power of wind farms fluctuates throughout the day due to uncontrollable variation of wind speed. The relationship between the output power (P) of a wind energy conversion system and the wind speed (v) is nonlinear in nature, which can be expressed as.

$$P = 1/2\ \rho C_p A v^3 \quad (1)$$

where ρ is the air density,
Cp is the power coefficient,
A is the area of air passing through.

The nonlinear relation of P and v causes fluctuations in output voltage and frequency despite of the implementation of advanced power-electronic-based controller. Thus, when such wind farms are connected to any high-voltage TLs, the distance relays protecting such lines are affected due to the fluctuations of voltage and frequency. In this article, DFIGs are used for extracting electrical energy from wind turbines. The parameters of different components of the studied system are provided. In the present article, the distance relay R1 at Bus-S of Fig. 2 is considered for performance evaluation. In the first case study, three different fault cases are generated during three different operating modes of the UPFC keeping only Source-1 and Source-2 in operation. The three fault cases considered are: 1) an ag-fault (fault resistance, rf = 10 Ω), initiated at 70% length of the line during STATCOM mode of operation, 2) an ab-fault, initiated at 80% length of the line during SSSC mode, and 3) a three-phase fault, initiated at 90% length of the line during UPFC mode of operation.

IV.CONCLUSION

By varying the series inverter's injected voltage's magnitude and phase angle, the transmission line's actual and reactive power flows may be modulated. When used in conjunction with a series inverter, the parallel inverter's primary purpose is to provide the actual power needed by the series inverter. Reactive power may be generated or absorbed by the parallel inverter in many ways. In order to better understand as well as compare the UPFC's functions, as well as to obtain the best control approach for active and reactive power flow in the power source, this paper offered most papers that used a UPFC to carry out the following point after locating an optimal location for the FACTs device, as described above.

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