

# A Review of UPFC Applications in Improving Power System Stability

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**Abstract:** The stability of power systems has been one of the major concerns of modern electrical power systems. The UPFC, a versatile FACTS controller, allows simultaneous or independent control of parameters like line impedance, voltage or power angle so that it can be used for voltage support, transient/dynamic stability improvement and damping of low frequency power system oscillations. This paper presents a review of various applications which UPFC provides in a power system such as minimization of loss, enhancement of loadability, voltage stability, transient stability, damping of power oscillations etc. by setting up UPFC parameters. To seek better power flow control, optimal allocation and parameter settings of UPFC in power system can be done by various evolutionary techniques.

**Index Terms:** FACTS, MATLAB, Simulink, Dynamic/Transient stability, Two-area power system, UPFC

## I. Introduction

The power system is a complex network comprising of numerous generators, transmission lines, variety of loads and transformers. As a consequence of increasing power demand, some transmission lines are more loaded than was planned when they were built. With the increased loading of long transmission lines, the problem of transient stability after a major fault can become a transmission limiting factor. Recent development of power electronics introduces the use of FACTS controllers to enhance controllability and increase of power transfer capability in a very fast manner. FACTS has number of benefits, such as greater power flow control, increased secure loading of existing transmission lines, damping of power oscillations, less environmental impact etc. FACTS controllers like Static VAR Compensator (SVC), Static Synchronous Compensator (STATCOM), Thyristor Controlled Series Capacitor (TCSC), Static Series Synchronous Compensator (SSSC), UPFC, IPFC etc. are capable of controlling the network condition in a very fast manner to improve voltage stability and power quality.

## II. Overview of FACTS Devices in Power System

FACTS controllers are used for dynamic control of line impedance, voltage or power angle of high voltage AC transmission line.

### 1. Static VAR Compensator (SVC):

It is a first-generation FACTS device that can control voltage at the required bus thereby improving the voltage profile of the system. The primary task of an SVC is to maintain the voltage at a particular bus by means of reactive power compensation. SVCs are also used to dampen power swings, improve transient stability, and reduce system losses by optimized reactive power control.

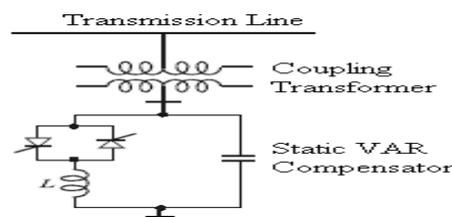


Fig. 1 Configuration of SVC

### 2. Static synchronous compensator (STATCOM):

It is a power electronic device using force commutated devices like IGBT, GTO etc. to control the reactive power flow through a power network and thereby increasing the stability of power network. STATCOM is a shunt device i.e. it is connected in shunt with the line. It consists of a voltage source converter (VSC), a coupling transformer and a dc capacitor. DC Capacitor is used to supply constant DC voltage to the voltage source converter, VSC. A Transformer is connected between the output of VSC and Power System. Transformer basically acts as a coupling medium. In addition, Transformer neutralize harmonics contained in the square waves produced by VSC. The voltage-source converter is used to convert the DC input voltage to an AC output voltage.

Two of the common VSC types are as below.

- Square-wave Inverters using Gate Turn-Off Thyristors: In this type of VSC, output AC voltage is controlled by changing the DC capacitor input voltage, as the fundamental component of the converter output voltage is proportional to the DC voltage.
- PWM Inverters using Insulated Gate Bipolar Transistors (IGBT): It uses Pulse Width Modulation (PWM) technique to create a sinusoidal waveform from a DC voltage source with a typical chopping frequency of a few kHz. In contrast to the GTO-based type, the IGBT-based VSC utilizes a fixed DC voltage and varies its output AC voltage by changing the modulation index of the PWM modulator.

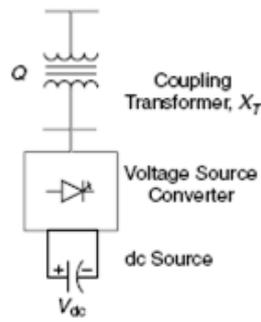


Figure 2. A GTO-based STATCOM

**3. Thyristor controlled series capacitor (TCSC):**

It is one of the most important and best-known FACTS devices, which has been in use for many years to increase the power transfer as well as to enhance system stability. The main circuit of a TCSC is shown in Fig. 3. The TCSC consists of three main components: capacitor bank C, bypass inductor L and bidirectional thyristors SCR1 and SCR2. The firing angles of the thyristors are controlled to adjust the TCSC reactance in accordance with a system control algorithm, normally in response to some system parameter variations. According to the variation of the thyristor firing angle or conduction angle, this process can be modelled as a fast switch between corresponding reactance's offered to the power system.

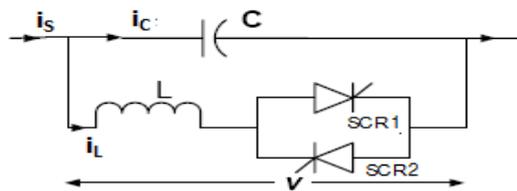


Fig. 3 Configuration of a TCSC

**4. Static Synchronous Series Compensator (SSSC):**

It is a member of FACTS family which is connected in series with a power system. It consists of a solid-state voltage source converter which generates a controllable voltage at fundamental frequency. When the injected voltage is kept in quadrature with the line current, it can behave as inductive or capacitive reactance so as to influence the power flow through the transmission line. While the primary purpose of a SSSC is to control power flow in steady state, it can also improve transient stability of a power system

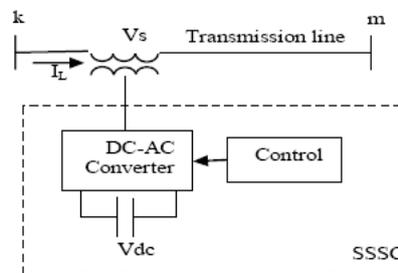


Fig.4 Simplified diagram of a SSSC

**5. Unified Power Flow Controller (UPFC):**

It is the most versatile one that can be used to improve steady state stability, dynamic stability and transient stability. The UPFC can independently control many parameters since it is the combination STATCOM and SSSC. These devices also offer an alternative mean to mitigate power system oscillations

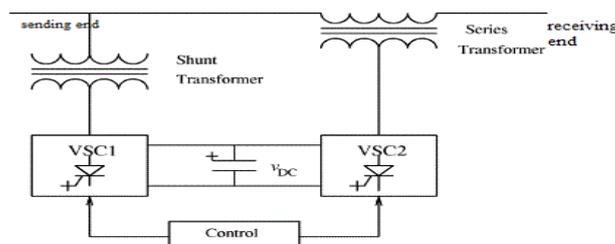


Fig. 5. UPFC

**III. UPFC Controller**

In (1994) Gyugyi introduced UPFC, which is capable of generating internally the reactive power necessary for network compensation, and is also able to interface with an appropriate energy storage device to negotiate real power exchange with the ac system. It uses solid-state synchronous voltage sources (GTO) for shunt compensation, series compensation, and phase angle control. UPFC controls all three network parameters (voltage, impedance, transmission angle) determining power transmission [1].

The UPFC as shown in figure 6 consist of two fully controlled inverters, series inverter is connected in series with the transmission line by series transformer, whereas parallel inverter is connected in parallel with the transmission line by parallel transformer, connected to each other by a common dc link including a storage capacitor. The real and reactive power flow in the transmission line can be controlled by changing the magnitude (0 to  $V_{SR}$  max) and phase angle (0 to 360) of the injected voltage ( $V_{SR}$ ) produced by the series inverter. The basic function of the parallel inverter is to supply the real power demanded by series inverter through the common dc link. The parallel inverter can also generate or absorb controllable reactive power.

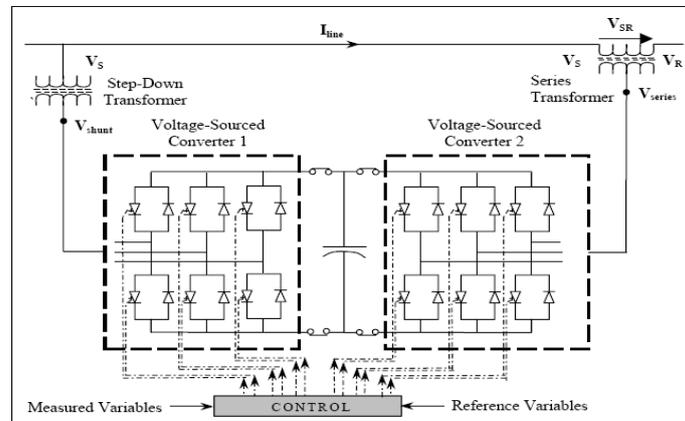


Figure 6. Schematic diagram of UPFC

In general, the shunt inverter will be operated in Automatic Voltage Control mode and the series inverter in Automatic Power Flow Control mode.

- Automatic Voltage control mode-In this case, Shunt converter reactive current is automatically regulated to maintain transmission line voltage to reference value at the point of connection
- Automatic Power Flow Control Mode- in this case, Magnitude and angle of  $V_{SR}$  is controlled so as to force a line current, that results in desired real and reactive power flow in the line.  $V_{SR}$  is determined automatically and continuously by closed loop control system to ensure desired P and Q.

#### IV. Role of UPFC in Improving Performance of Power System

In 1995, Gyuqi and et al. described the basic concepts of the proposed generalized P and Q controller and compares it to the thyristor-Controlled Series Capacitor and Thyristor-Controlled Phase Angle Regulator. They also present results of computer simulations showing the performance of the UPFC under different system conditions [2].

In (1996) Round, and et al. studied the performance of a unified power flow controller (UPFC) with four different controllers and evaluated through simulation and implementation in an experimental laboratory model. The controllers which were investigated are the PI controller, PI controller with decoupling, cross-coupling controller and robust  $H_\infty$  controller. It is found that the cross-coupling and Robust  $H_\infty$  controllers have the best performance when the exact value of the power transmission parameters is unknown [3].

In (1997) M. Noro Ozian, et al. deal with optimal power flow control in electric power systems by use of unified power flow controller (UPFC). And they developed and analyzed Models suitable for incorporation in power flow programs. And demonstrated the application of UPFC for optimal power flow control through numerical examples. It is shown that a UPFC has the capability of regulating the power flow and minimizing the power losses simultaneously [4].

In (2000) Zhengyu Huang, et al. discuss four principal main control strategies and the computer tests results support the discussion conclusion and also, they concluded the constant power flow control is good for steady state control and the constant series compensation control is useful for first swing stability. The supplementary control is very efficient in damping the power oscillation. The suggested UPFC control can realize the desired control strategy flexibly and improve system dynamic performance significantly [5].

In (2010) Muthukrishnan and Kumar deal with digital simulation and implementation of power system using UPFC to improve the power quality. They deduce that UPFC is also capable of improving transient stability in a power system [6].

In (2010) Mathukrishnan and kumar deal with digital simulation of 14 – bus power system using UPFC to improve the power quality. They conclude that the UPFS has the capability of improving the transient stability in a power system [7].

In (2010) Murali, and et al. investigates the improvement of transient stability of a two-area power system using UPFC and simulations are carried out in Matlab/Simulink environment for the two-area power system model . The performance of UPFC is compared with other FACTS devices such as Static Synchronous Series Compensator (SSSC), Thyristor Controlled Series Capacitor (TCSC), and Static Var Compensator (SVC) respectively. The simulation results demonstrate the effectiveness and robustness of the proposed UPFC on transient stability improvement of the system [8].

In (2011) Arup Ratan Bhowmik and Champa Nandi investigated the performance of Unified Power Flow Controller (UPFC) in controlling the flow of power over the transmission line and they dialed with digital simulation of standard IEEE 14-bus power system using UPFC to improve the real and reactive power flow control through a transmission line by placing UPFC at the sending end [9].

In (2012) Aarti Rai includes first the optimal location of FACTS devices, second voltage stability analysis and third control of reactive power of system. The model can be simulated in MATLAB. The performance of the whole system such as voltage stability, transient stability, frequency and power swings are analyzed and compared without FACTS and with FACTS device [10].

In (2013) Rama Sekhara Reddy and Vijaya Kumar used a Unified Power Flow Controller (UPFC) to control the power flow in

the transmission systems by controlling the impedance, voltage magnitude and phase angle in wind energy generation. This controller offers advantages in terms of static and dynamic operation of the power system [11].

In (2013) Hakim Elahi Tooraji and Nekoubin Abdolamir designed and simulated a Unified Power Flow Controller in multi-machine power system. The on-line designed process is based on PWM method which all the power quality parameters representing as voltage sag and swell can be improved. In the proposed control method, the harmonic distortion of the system is decreased and the voltage oscillations of the DC capacitor will be improved. Simulations that are done by the PSCAD/EMTDC software show the effectiveness and precision of this [12].

In (2013) Kumar Gaurav and Nitin Saxena investigate the enhancement in voltage stability margin as well as the improvement in the power transfer capability in a power system with the incorporation of UPFC. A simple transmission line system is modeled in Matlab/Simulink environment. The load flow results are first obtained for an uncompensated system, and the voltage and power profiles are studied. The results so obtained are compared with the result obtained after compensating the system using UPFC to show the voltage stability margin enhancement [13].

In (2013) Vaibhav S Kale et, al. proposed the real, reactive power and voltage control through a transmission line by placing UPFC at the sending end using computer simulation. The control scheme has the fast dynamic response and hence is adequate for improving transient behavior of power system after transient conditions [14].

In (2013) K.Ravichandrudu and et al. introduced the concept of Distributed FACTS (D-FACTS) as an alternative approach to realizing cost-effective power flow control. They concluded that the UPFC is capable of improving transient stability in a power system and it is the most complex power electronic system for controlling the power flow in an electrical power system. The circuit model is developed for UPFC using rectifier and inverter circuits. The control angle is varied to vary the real and reactive powers at the receiving end [15].

In (2013) K. Ravichandrudu et, al. demonstrated the performance of the UPFC in achieving harmonic mitigation and stability of the wind energy grid by using MATLAB/SIMULINK [16].

In (2014) B.Gopinath et, al. proposed a method based on Model predictive control (MPC) and using Bacterial Forging Algorithm (BFA) for modeling Unified Power Flow Controller. Modeling of UPFC is designed with its unique capability to control simultaneously real and reactive power flows on a transmission line as well as to regulate voltage at the bus where it is connected. Therefore, this device creates a remarkable quality impact on power system stability. UPFC with additional PI controller is used along with the UPFC main controller . [17].

In (2015) Koganti et, al. studied Power quality and stability improvement of HVDC transmission System using UPFC for Different uncertainty conditions, they concluded that UPFC improves the system performance. It can control the power flow in the transmission line, effectively. With the addition of UPFC, the magnitude of fault current reduces and oscillations of excitation voltage also reduce. The total harmonic distortion (THD) is also reduced well below the IEC standards. It is more economical for the HVDC transmission system to transfer more power [18].

In (2015) Shantha Soruban et, al. proposed an ANN based control scheme for a UPFC to be used as an active power filter. The objective is to guarantee power to the load at the required power quality. The ANN control unit monitors the voltage at the point of common coupling. UPFC enables improved power quality by maintaining power factor nearer to unity rapid response time, the ability to provide reactive power at low voltage and to provide voltage compensation can be obtained. For unbalanced voltage compensation, two unbalanced controllers using the phase voltage amplitude and negative sequence component are proposed [19].

#### **V. Different control techniques for better P and Q control**

In 2015 Priyankakarwa, V.P.Rajderkar deals with the optimal placement of UPFC to maximize power transfer capability. Real power sensitivity performance index has been used to find optimal location of UPFC on IEEE-5 and IEEE-14 bus system. [20]

In 2017. Kyaw Myo Lin, proposes a set of load curtailment sensitivity indices for optimal placement of Unified Power Flow Controller (UPFC) in power system network. [21]

In 2010 Suppakarn Chansareewittaya and Peerapol Jirapong proposes particle swarm optimization (PSO) technique to determine the optimal allocation of multi-type FACTS controllers to enhance power transfer capability of power transactions between sources and sink areas in power systems. [22]

In 2014 Sreerama Kumar R., Ibrahim M. Jomoah, and Abdullah Omar Bafail proposes the application of genetic algorithm for the determination of the optimal placement of unified power flow controller (UPFC) in a power system so as to minimize the system losses and enhance the voltage profile. [23]

In 2005 Weerakorn Ongsakul and Peerapol Jirapong, an evolutionary programming (EP) is proposed to determine the optimal allocation of FACTS devices for maximizing the total transfer capability (TTC) of power transactions between source and sink areas in deregulated power system. [24]

In 2013 R. Selvarasu and M. Surya Kalavathi, a new strategy has been proposed for optimal placement of Unified Power Flow Controller (UPFC) in power systems with a view to minimize the transmission loss. The proposed strategy uses Self Adaptive Firefly Algorithm (SAFA) and identifies the optimal locations for UPFC placement and their parameter. Simulations results are presented for IEEE 14-bus system and IEEE 30-bus system. Results have shown that the identified location of UPFC minimize the transmission loss in the power system network [25]

In 2008 Sreekanth Reddy Donapati and M.K.Verma proposes a sensitivity based technique for optimal placement of Unified Power Flow Controller (UPFC) to enhance voltage stability margin under contingencies. [26]

In 2011, Kiran et al. proposed Particle swarm optimization method to solve the optimal power flow problem on power system by finding a location for UPFC device. The proposed algorithm is an effective method for finding the optimal choice and location of UPFC controller and also minimizing the overall system cost, which comprises of generation cost and the investment cost of the UPFC controller using PSO and conventional Newton Raphson's power flow method by verifying it on IEEE 14 bus test system. [27]

Saravanan et al. proposed the application of Particle Swarm Optimization to find the optimal location, settings, type and number of FACTS devices including UPFC to minimize its cost of installation and to improve system loadability for single and multi-type FACTS devices. [28]

Singh et al. suggested the suitable locations of UPFC to enhance system loadability and tested it on IEEE 14 bus system. A sensitivity-based approach has been developed for finding suitable placement of UPFC. [29]

Shaheen et al. presented application of evolutionary optimization techniques for optimal location and parameter setting of multiple UPFC devices for maximizing loadability and minimizing installation cost in power system with respect to line thermal limits and bus voltage magnitude limits. This proposed method was tested on IEEE 6 and IEEE 14 bus test power system with desired results. [30]

Abdullah et al. presented the application of evolutionary computation technique for monitoring voltage profile of the power system network when UPFC is incorporated in the network. Evolutionary Programming and Artificial Immune system method have been applied in IEEE 30 bus RTS system to maintain stable voltage profile and minimize losses while increasing the power transfer capability. [31]

Taki et al. discussed the application of neuro –fuzzy controlled UPFC to improve transient stability of power system. Proposed method is tested on a single machine infinite bus system to confirm its performance through simulation. By keeping the series (shunt) branch inactive, UPFC can operate as a STATCOM (SSSC) and the corresponding behavior is also evaluated and compared. The superiority of the proposed controlled UPFC over a STATCOM or a SSSC in improving transient stability of a single machine infinite bus has been demonstrated. [32]

Hosseini et al. proposed a transient model and control system of UPFC to enhance the voltage regulation and transient stability of a radial AC transmission system using UPFC. The control scheme has the fast dynamic response and therefore, improves the transient behavior of power system after a transient condition. Simulation results demonstrate that the presented control system acts properly in steady state and transient condition. The presented UPFC control system can regulate line active and reactive power flow and voltage at line midpoint. The presented control system of UPFC not only responses to the step changing in the active and reactive power, but also is able to exchange the direction of line active power flows. Also, the proposed control system is regulating the DC link capacitor voltage. The simulation results indicate the fast dynamic response, validity and effectiveness of the presented control scheme. [33]

## 6. Case Study

Using Kundur two area power system [34] simulation results in MATLAB/SIMULINK platform shows the effects of UPFC on transient stability performance of the system. The performance of UPFC is compared with other FACTS devices such as Static Synchronous Series Compensator (SSSC), Thyristor Controlled Series Capacitor (TCSC), and Static Var Compensator (SVC). The simulation results demonstrate the effectiveness and robustness of the UPFC on transient stability improvement of the system which is shown in Table 1 [8]. It is clear from the simulation results that with the presence of UPFC, the settling time in post fault period is found to be around 0.6 second.

Table 1: Comparison of FACTS Devices

Two-area Power System with	Power System Stability Enhancement	Settling time in post fault period (in seconds)
SSSC	YES	11
SVC	YES	7
TCSC	YES	1.5
UPFC	YES	0.6

## 7. Conclusion

Using various techniques, optimal allocation of UPFC can be done to enhance stability of power system. Some of the applications of the UPFC are as under-

- Improving the active and reactive control power flow of the power systems / optimal power flow control.
- Increasing the transient stability,
- Increasing the damping of oscillations.
- Controlling the steady state or dynamic performance.
- Optimizing power flow / minimization of power loss
- Minimizing the operational costs of the electrical grid.
- Enhancement of system load ability / transmission capability
8. Enhancement of voltage profile

It is also found from the case study that the UPFC is more effective for improving power system stability as compared to other FACTS devices.

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