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EFFECTIVINESS OF FACTS DEVICES FOR THE CONTROL OF POWER SYSTEM TRANSIENT STABILITY USING DIFFERENT INTELLINGENT TECHNIQUES.

Alfred, B. Baams,
Department of Electri cal/Electronics Engineering Modibbo Adama University of Technology, Yola Ada mawa State, Nigeria
Email: albams2006@yahoo.com

Dr. J. Usman,
Department of Electrical /Electronics Engineering, University of Maiduguri, Nigeria.
Email: jafaruu@unimaid.edu.ng

Simon Samuel
Department of Electri cal/Electronics Engineering Modibbo Adama University of Technology, Yola Ada mawa State, Nigeria
Email: smonsamel40@yahoo.com

Ishiwu I. Jude
Department of Electri cal/Electronics Engineering Modibbo Adama University of Technology, Yola Ada mawa State, Nigeria
Email: judeclinton30@gmail.com

Abstrac: This paper is aimed towards the benefits of utilizing flexible Alternating current transmission system (FACTS) devices using different intelligent techniques with the purpose of improving the operation of an electrical power system. Voltage instability is considered as a main threat to stability, security and reliability in the modern power systems. The application of FACTS controllers has been for the purpose of maximizing the lines conductivity given the restrictions involved, including the issue of stability. The main causes of voltage instability and solutions have been reviewed [29]. Hence, effectiveness of the proposed techniques employed is robust to different operating conditions and disturbances. Performance comparison of different FACTS devices has been discussed. Semiconductor technology development and utility experience have been reviewed and summarized. The used and installation of FACTS devices on the power transmission lines has been discussed. This survey article will be very much useful to the researchers for finding out the relevant references in the field of voltage stability enhancement by using FACTS devices in power transmission system.

Keywords: FACTS Devices, Intelligent Techniques, Reliability, Security, Stability,

1. INTRODUCTION

The rapid increasing of power demand and expansion of transmission network day by day, it affects the complexity to maintain the stability of electricity [4]. Nowadays energy systems are highly complex and widespread that operates much closer to their breakdown limits, due to economic, environmental, political and technical factors (e.g power losses and fluctuations). Despite the fact that the volume of power transmission and power consumption have been increasing in non-uniform use of facilities, unwanted pathways or rings and as well as transmission corridors, has affected or limited the growth in power transmission [14]. FACTS technology is considered as important devices to make full use of available transmission facilities in emergencies with no security problem in the system, interesting feature of these facilities is direct control of the power passing through transmission lines by changing parameters of grid structure via high-gain control systems based on fast switching [1]. Unsuitable location of FACTS devices, high reactive power consumption at heavy loads, occurrence of contingencies and reverse operation of ON load tap-changer (OLTC), also the voltage sources are far from load centers and improper coordination between multiple FACTS controllers constitute instability of power systems [9].

The FACTS devices gives a great opportunity to regulate the transmission of AC signal which increases or diminishing the power flow in specific lines, and responding almost instantaneously to the instability by placement of series and shunt devices on the route of power flow, and generation rescheduling [22]. Also installation of FACTS controller under-voltage load shedding. The tap-changer is to block reverse operation. The multiple FACTS devices are suitable, coordinating, and installation of synchronous condensers for the improvement of power supply [16]. Flexible alternating current transmission system (FACTS) is generally power electronics based devices which build-up of thyristor valve and voltage source converter (VSC) [21]. Under the FACTS devices it has three stages such as; shunt series, shunt and series devices. The thyristor valve consist of SVC, TCSC, DFC and HVDC B2B and voltage source converter (VSC) are; STATCOM, SSSC, UPFC/IPFC and HVDC B2B. These devices are wisely coordinated to dynamically adjust the Network configuration to enhance steady-state performance as well as dynamic stability [9]. The FACTS controller can provide variable turn and/or series compensation by coordinating with one another. The insufficient of electric energy can be overcome or minimized by using the technology of FACTS controller [19]. Stability is the ability of the system to develop restoring forces equal to or more than the disturbing forces and remain stable when subjected to the disturbance [3]. The applications of the FACTS controllers in power system has really help in the improvement of power transmission system as well as provide operating flexibility to the power system [20]. However, these FACTS technology helps the industries to better utilize existing generation and transmission reserves with the good power system performance [1]. The coordination of FACTS technology such as gate turn-off thyristor-switching converters (GTO), thyristor controlled series capacitor (TCSC), thyristor controlled phase shifter (TCPS), static synchronous compensator (STATCOM), static synchronous series compensator (SSSC), unified power flow controller (UPFC) and the interline power flow controller (IPFC), are used for the enhancement of transmission network capability. They are interfaced to power system at appropriate location of the transmission lines, in series, shunt or in combination of series and shunt [12].

2. FACTS DEVICES

2.1 Thyristor-Controlled Series Capacitor

Thyristor-controlled series capacitor (TCSC) is an important device in the family of FACTS devices, which uses thyristor-controlled reactor (TCR) in parallel with capacitor segments of series capacitor bank [4]. TCSC is slightly different from SVC. TCSC address specific dynamic problems in transmission system, by increases the damping when large electrical systems are interconnected and as well as overcome the problem of sub-synchronous resonance (SSR), a phenomenon that involves an interaction between large thermal generating units and series compensated transmission system [18]. TCSC is directly connected to the AC transmission line, whose capacity of power transmission has to improve. It is connected by series connection with main line. Static voltage stability margin enhancement using TCSC says the combination of TCR and capacitor allows the capacitive reactance to be smoothly controlled [14]. The controlled impedance can be programmed in a way that it can react in a distinct method in emergencies and increases power system security [15]. TCSC in transmission system is adopted in order to balance natural load in parallel transmission lines for maximum transmission capacity. Transmission active power depends on transmission line reactance [17].

$$P = |V_1||V_2|\sin(\alpha_1 - \alpha_2) / \text{X} \qquad (1)$$

The impedance of grid series is adjustable through thyristor controllers that changed the power transmission. The basic circuit of TCSC [11] is shown in figure 1.

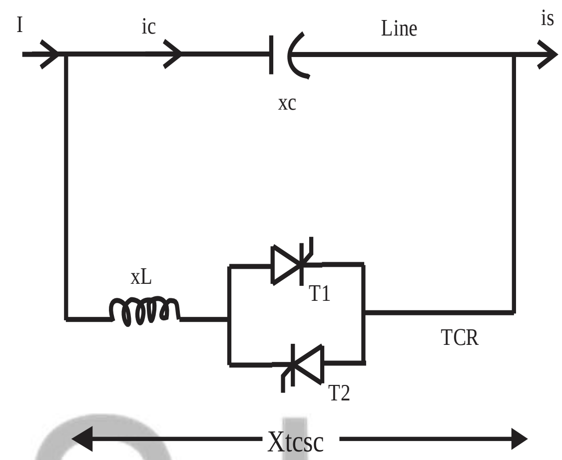

Figure 1: TCSC basic circuit

Due to the variation in conductance angle (α), it can be modeled as a fast switch inline with the reactance of power system. The modeled TCSC is shown in fig.2 below;

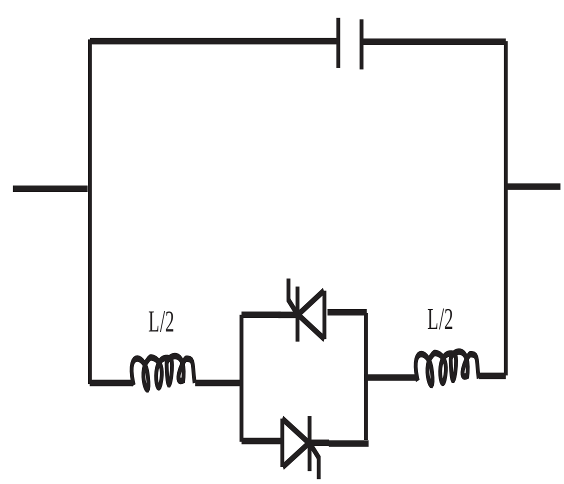

Figure 2: Modeled TCSC

The increase or decrease in thyristors' conductance period and consequently, the current passing through TCR is controlled by compensation degree of series [16]. The difference in electric angle between the positive voltage passing through zero and the current passing through zero is called the firing angle (α) of TCR. α<90˚ no control over inductive current. α>180˚ is not possible for thyristors because of limitation in thyristors' symmetrical firing [5]. TCSC reactance is obtained as

$$X_{TCSC} = (X_C X_L)/ (X_c/n)\ [2(\pi-\alpha) + \sin 2\alpha] - X_L \qquad (2)$$

Where, α, X_C and X_L denote firing angle of thyristor, capacitor reactance. TCSC is connected in series in the transmission line with relation to reactance of the transmission line.

$$X_{ij} = X_{Line} + X_{TCSC} \qquad (3)$$

For TCSC to have a better modeling in optimization, we have

$$X_{TCSC} = R_{TCSC} * X_{Line} \qquad (4)$$

Where R = compensation factor of TCSC it varies based upon where exactly is connected on transmission line ranging between -0.7 and 0.2 schematic view of TCSC [14] is shown in figure 2.

2.2 Unified Power Flow Controller

The Unified Power Flow Controller (UPFC), act as a shunt compensating and a phase shifting device because it is a combination of a static compensator and series compensation. It has the best effect on efficient steady state transmission [12]. Also, it has ability to adjust the three control parameters, i.e the bus voltage, transmission line reactance and phase angle between two buses, either simultaneously or independently [23]. UPFC has two voltage source inverters and a common capacitor between them, and they are connected to the grid in series/parallel by two transformers. This technology is setting effect on steady state, dynamic and transient stabilities [11]. The UPFC is the most versatile and complex power electronic equipment that has emerged for the control and optimization of power flow in electrical power transmission system [8]. UPFC provide multifunctional flexibility required to solves many of the problems facing the power industry [10]. The UPFC circuit is shown in figure 3.

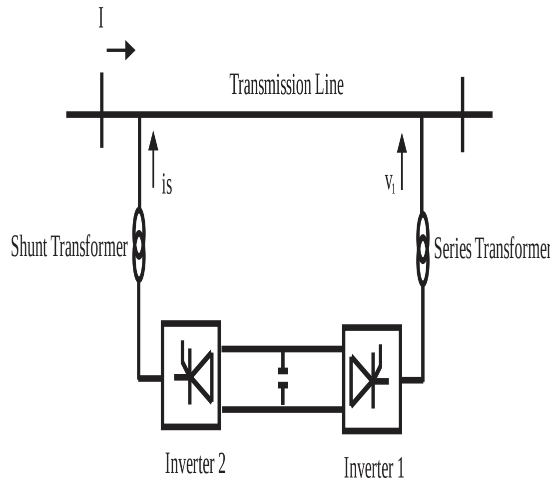

Figure 3: UPFC Structure

The UPFC is modeled in two ways, coupled and decoupled model. Coupled model is more complicated, is corrected here by Jacobian matrix whereas, decoupled model load dispersion algorithms without need to correction or simplification of Jacobian matrix was used [7]. The latter model has adopted, see figure 4.

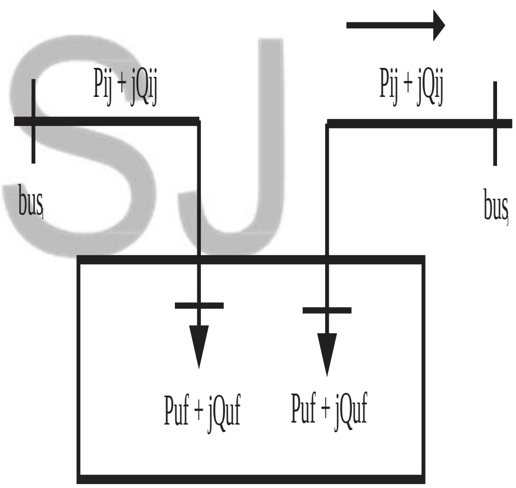

Figure 4: Decoupled model of UPFC

2.3 Static Synchronous Series Compensator

The Static Synchronous Series Compensator (SSSC) is a series voltage source, which work the way as the STATCOM, but this device is more complicated because of the platform mounting and the protection [5]. A thyristor protection is necessary due to the over load capacity of the semiconductors especially when IGBTs are used [8]. SSSC is connected to a transmission line by series connection through a transformer. It is an energy source to provide a continuous voltage through a condenser and compensate the losses of the VSC. This device is then called dynamic voltage restorer (DVR), which is used to keep the voltage level constant e.g factory in feed [9]. Hence, with the charging mechanism or battery on the DC side, the device can work as UPS (uninterruptible power supply). SSSC, with reactive power compensation only the voltage is controllable, because the voltage vector forms 90˚(degrees) with the line intensity [6]. This means that the SSSC can be uniformly controlled in any value, in the VSC working slot, as shown in figure 5.

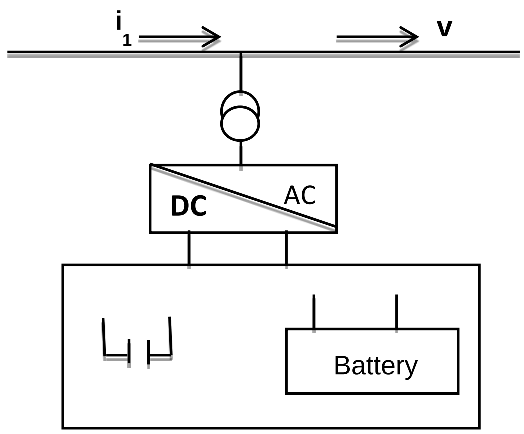

Figure 5: Static Synchronous Series Compensator (SSSC).

2.4 Static VAR Compensator

The term ‘static’ refers to the fact that the Static VAR Compensator (SVC) has no moving parts other than circuit breakers, which do not move under normal SVC operation. It is connected with the transmission line in parallel connection, which works as a generator as well as a load for the transmission line; the primary purpose is quick control of voltage at its weak point of the network [8]. A rapid operating static VAR compensator (SVC) can provide the reactive power required to control dynamic voltage oscillations under various system conditions, and thereby improve the power system transmission and distribution stability [20]. The SVC increase transfer capability and reduce losses, also smooth voltage profile is maintained under different network conditions, when installed at one or more points in the network [11]. The SVC is an automatic impedance matching device, designed to bring the system closer to unity power factor. If the power system’s reactive load is capacitive, the SVC will use reactors to consume VARs from the system, lowering the system voltage under inductive conditions, the capacitor banks are automatically switched in. Thus providing a high system voltage, SVC consists of a TCR (reactive impedance in $\mathbf{X_L}$ with a two-way valve-thyristor) parallel with capacitor bank $\mathbf{X_C}$ and it adjusts the voltage of connecting point to the grid as a parallel varying reactance by absorbing or producing reactive power, it is mostly applied to provide reactive power very fast and to support voltage by controlling firing angle of thyristor [10]. Circuit diagram is shown in figure 6.

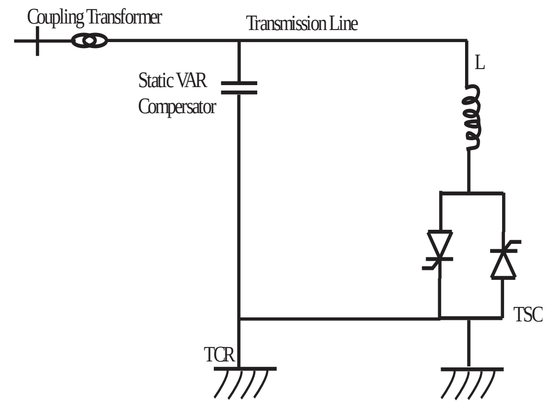

Figure 6: Representation of FC-TCR (SVC) Circuit.

It is connected through a coupling transformer with the main AC transmission line whose voltage has to be regulated. SVC is made by the combination of controllable, by controlling the firing angle of thyristor. Controllable of TCR reactance, $\mathbf{X}_V$ is derived [7] as

$$X_V = \pi / (2\pi - 2\alpha + \sin 2\alpha) \quad (5)$$

α = firing angle of the thyristor

Effective susceptance B in TCR is obtained as

$$B = (X_V + X_C)/(X_V X_C) \quad (6)$$

2.5 Static Synchronous Compensator:

Static Synchronous Compensator (STATCOM) is built with thyristors, with turn-off capability like GTO or with more and more IGBTs. A STATCOM is a regulating device used on grid network. Static synchronous compensator (STATCOM) acts as a source of reactive power to transmission network which was based on electronics voltage source converter. It provides active AC power if connected to a source of power [21]. A poor power factor of an electricity network is supported by installing STATCOM and often poor voltage regulation compensator (STATCOM) has characteristics similar to the synchronous condenser, but as an electronic [7]. Static synchronous device has no inertia and is superior to the synchronous condenser in several ways, such as better dynamics, a lower investment cost, lower operating and maintenance costs [18]. Advantage of a STATCOM is that, the reactive power provision is independent from the actual voltage on the connection point. The combination of active and reactive power improves the performance for power quality and balanced network operation. The most common use is for voltage stability, and as well provides better damping characteristics than the SVC as it is able to transiently exchange active power with the system [2].

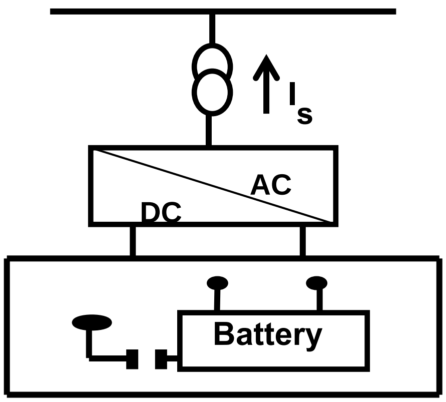

Figure.7: STATCOM Structure

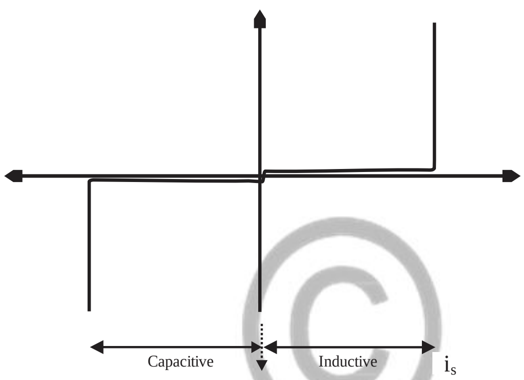

Figure 8: Voltage/Current characteristics

2.6. Comparing TCSC and UPFC.

In terms of their influence on system reliability, comparison is made to confirm the difference of both TCSC and UPFC. TCSC has the ability to control active power in power system [11]. The continuous varying capacitor whose impedance range in 0 ≤ XG ≤ ZC maximum is by the TCSC, which controllable series capacitor impedance can reduce a part of inductive reactance in transmission line and decrease total impedance of transmission line and consequently, increase transmissible power [13]. Increased in transmissible power is a fixed percentage of transmitted power by uncompensated line in a given transmission angle. This associated with the fact that TCSC is series impedance and the compensated voltage by TCSC is dependent on transmission line current, whereas UPFC is a voltage source and compensated voltage by UPFC is not dependent on line current, it is dependent on maximum series voltage by UPFC. Assumed TCSC is connected to the transmission line $\mathbf{L_1}$ in series. Compensation angle is in such a way that total inductive reactance of line $\mathbf{L_1}$ equals half of inductive reactance $\mathbf{L_2}$, moreover, it is assumed that reliability of TCSC and UPFC is 100%, by reducing transmission angle and using TCSC, transmitted power from $\mathbf{L_1}$ and $\mathbf{L_2}$ are 1.5P and 0.75P [14] figure. 7 TCSC vs UPFC (reliability related to two situation).

2.7 Integral Power Flow Controller

Integral Power Flow Controller (IPFC) controlled the power flows of two lines starting in one substation. The IPFC consists of two series VSCs whose DC capacitors are coupled, which permits active power to circulate between VSCs. To optimize the network utilization two lines can be simultaneously controlled [1]. In the general conceptual frame work of the convertible static compensator (CSC), two multi-converters FACTS-devices, such as, integral power flow controller (IPFC) and generalized unified power flow controller (GUPFC) are among many possible configurations, with the target to control power flows of multi-lines or sub network, rather than controlling the power flow of a single line, for instance, the use of DFC or UPFC [17]. Two or more series converters are combined by integral power flow controller (IPFC), whereas only one shunt converter is combined by generalized unified power flow controller (GUPFC) [22]. Therefore, the current NYPA's CSC installation is a two converter in one and can operate as an IPFC. The CSC is the latest FACTS devices which were installed recently as a pilot by the New York Power Authority (NYPA), mainly to increase power transfer capability and maximize the use of the existing transmission Network [4]. Hence, for IPFC two series VSCs connected to each other at the DC bus, one of them (assumed as the master VSC) can control both line active and reactive power and the other one (assumed as the slave VSC) can only regulate power line, by supporting sufficient active power to the master VSC through the DC tie [2]

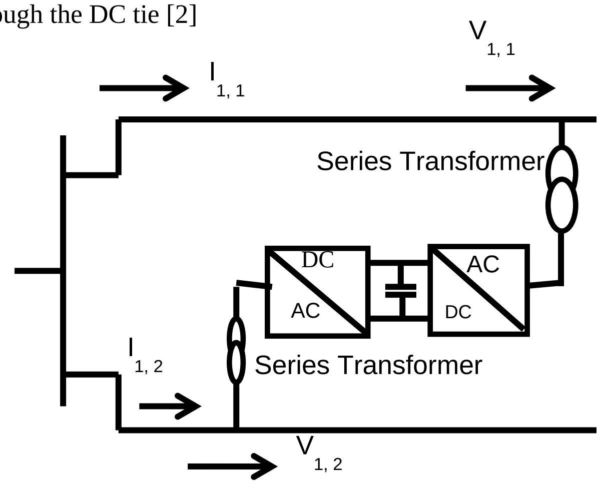

Figure 9. Configuration of an IPFC

2.8 Distributed Power Flow Controller

Distributed Power Flow Controller (DPFC) is a hybrid device between a phase shifting transformer (PST) and switched series compensation. Due to the high voltage, high power (multi-hundred MVA) and high cost, the device is not widespread. The DPFC has the following major components such as; single turn transformer, single phase voltage source inverter, filter and controlling module, self-production module [18]. The introduction of the DPFC was the proposed approach as an alternative for realizing the functionality of FACTS-devices. The DPFC designed proposal was derived from UPFC. So, the increase reliability of the system was due to the absent of a common DC link between the converters. The transmission lines at a third harmonic frequency resulted to active power exchange between series and shunt converter [7]. The DPFC device is rated about 10KVA, with the devices connected on the transmission line. Here, the steady power flow is achieved by increasing or decreasing the impedance of the line [15]. The reactance of the DPFC is exchanged based on the AV1. The port network formed by AB to meet the flux and current of inductance is equivalent to the inductance and transformer which can also be controlled by the negative inductance. AV1 is proportional to L with the large number of modules working together, gives better effect on the overall power flow in the line [4].

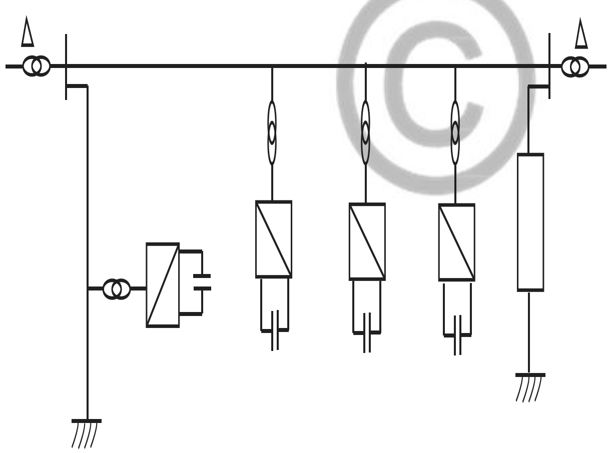

Figure 10. Distributed power flow controller (DPFC)

3. STABILITY IN POWER SYSTEM NETWORK

Due to different devices and instruments used it is complex in nature to identify the stabilities and getting improvement on them. The classes of stabilities are many, depends on various factors of the power transmission system. Such as; voltage stability, frequency stability and rotor angle stability [9]. Voltage stability: the power system stability is the ability of the system to maintain steady current/voltage at all the transmission lines after encountered disturbance [11]. Here, the load demand and supply from the power system are able to maintain a balance. There are various voltage instabilities such as; voltage fluctuation, voltage losses, voltage drops, voltage surge, etc. this can be minimized by maintaining the condition of generators and other devices in good manner. Also good operating condition and design of machineries, equipments and skilled operated periodically maintenance. Voltage stability has two branches; large-interruption voltage stability and small-interruption voltage stability [20].

3.1 The Large-Interruption Voltage Stability: -

It is the ability of the system to manage steady voltages, subsequent large interruption being system faults, loss of generation or circuit exigency [2]. It can be resolved by the system and load characteristics, and interactions of both continuous and discrete control protections. The small-interruption voltage stability is to maintain steady voltages when subjected to minimum perturbations, it is clouted by the characteristics of loads, continuous control and discrete control at a given instant of time [5]. Frequency stability; it is assign to maintain steady frequency due to imbalance between generation and load, with minimum inadvertent loss of load, fluctuations that may conclusion ensue in the form of interrupted frequency swings well-known to trip of generating unit or load [7]. Rotor angle stability**;** it is the persistent in synchronism of synchronous machine of an interconnected power system network subsequently been subjected to an interruption [12]. The instability occurs due to an increasing angular swing of the generators or loss of synchronism with other generators. The loss of synchronism happens by the non-equilibrium state between mechanical torque, electromagnetic torque and speed difference between the generators [3].

4. IMPORTANTS OF USING FACTS CONTROLLERS

A new algorithm was developed by researchers in the previous years for addressing the optimal power system instability by applying FACTS devices. The SVC and TCSC of FACTS devices are modeled as controllable impedance. Whereas IPFC, SSSC, STATCOM, UPFC are modeled as controllable voltage sources [16]. The demand of electricity is increasing at a speedy rate without any enhancement of power transmission networks [6]. Therefore, deregulation of electricity will create an environment for forces of competition and bargaining [9]. The benefits of utilizing FACTS controllers in power systems are; effective utilization of transmission system assets. The availability and reliability of power transmission system increases, also dynamic and transient grid stability increased as well as reduction of loop flows and better quality of supply for sensitive industries. There has been an increased use of the FACTS devices applications in an electricity market having pool and contractual dispatches [13]

5. CONCLUSION

Flexible alternating current transmission system, provide an opportunity to control, stabilize, and elevate power capability in alternating current power system. Transmission and distribution of power energy are regarded as dynamic and growing aspects of engineering. The essential features of FACTS controllers and their potential to improve system stability is the prime concern for effective and economic operation of the power system. FACTS devices have established itself as a proven and mature technology. It is one of the most important too for the operational flexibility and controllability in system operator. FACTS technology is not a single powerful technology but it is a set of controllers, each is able to control one or some system parameters in isolation or in combination with other controllers. A properly selected FACTS devices can solve specific limitations of a given line or corridor. FACTS devices helps to better utilize the existing transmission resources, where the utilities are facing the problem of transmission expansion. This all indicates that there is a great potential for its application in future with literature survey it can be analyzed that the capability of FACTS devices power stability is achievable. The application of different intelligent technique of FACTS devices instability of electric energy system can be address.

6. ACKNOWLEDGMENT

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