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Study and Analysis of Power System Stability Based on FACT Controller System

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ABSTRACT

Energy framework soundness is identified with standards rotational movement and the swing condition administering electromechanical unique conduct. In the exceptional instance of two limited machines, the basis of equivalent territory security can be utilized to ascertain the basic clearing point in the force framework, It is important to look after synchronization, in any case the degree of administration for customers won't be accomplished. This term steadiness signifies "looking after synchronization." This paper is an audit of three kinds of consistent state. The main sort of adjustment, consistent state steadiness clarifies the most extreme consistent state quality and force point chart. The transient solidness clarifies the wavering condition and the idleness steady while dynamic soundness manages the transient security time frame. There are a few different ways to improve framework soundness a portion of the techniques are clarified. Versatile AC Transmission Frameworks (FACTS) Flexible AC Transmission System (FACTS) regulators have been utilized frequently to comprehend the different issues of a non-variable force structure. Versatile AC Transmission Frames or FACTS are devices that permit versatile and dynamic control of intensity outlines. Improving casing respectability has been explored with FACTS regulators. This examination focuses to the upsides of utilizing FACTS apparatuses with the explanation behind improving electric force tire activity. There has been discussion of an execution check for different FACTS regulators.

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1. INTRODUCTION

The The stabilization of the energy system is described as "the power system's ability to recover a state of operational stabilization after physical disruption for a given initial working conditions, With most device parameters bound such that the whole system stays virtually intact"[1]. According to the aforementioned description, if the device does not attain operational harmony, it is obvious that it is deemed instable. Power intake has elevated appreciably over the preceding decades, however, the improvement of electricity technology and transmission has been significantly curtailed because of the loss of sources in addition to environmental restrictions. As a result, positive transmission traces are excessively laden, and gadget balance will become a proscribing element in electricity transfer. So the reliability of the electricity gadget is turning into a key difficulty for operators, particularly the highly loaded energy systems with a shortage of reactive power. Power instability is a significant challenge to the safety, performance and reliability of power systems [2]. The power sources have become much more advanced and complicated because of varied sources of generation and distribution without altering or adding, in certain cases, forces the device to work in severe overstressed. Furthermore, the necessity of reactive capacity is becoming difficult to satisfy as well as to preserve the bus voltage is kept under acceptable limits[7].To greatly increase performance, power plant operators are coercive to step away from of the (traditional/conventional) paradigm of centralized energy sources, De-centralized far less controlled processes transmissions and distributions. This world propensity to deregulate power networks seeks to be more effective and competitive in an open-market setting. In this analysis, will focus on the energy system's distribution section and issues involving. Because of limited transmission line (TL) extension and growing generating problems, such as strongly overloaded lines, The unplanned distribution of power and the reliability of energy quite severe.

To solve these challenges, different varieties of technologies are implemented which can easily operate and effectively while at the same time alleviate the voltage stabilization problem and improve the power quality flow throughout the energy system. In current power system networks there's several types of instabilities (e.g. voltage, frequency, and so on.). Then accordingly the various stabilization approaches are therefore utilized. The stabilization mechanism operates effectively by compensating the volatility caused. In the previous this is achieved by connected and disconnected condensers, inductors or combination of both, next the synchronous capacitors saturation reactor.

Other specialized instruments such as STATCOM, VSC, and TCSC etc. are currently in operation. These equipment develop intelligent power controlling system, and quick switching devices such as MOSFET and IGBT, allow it possible to easily switch and provide reliable and efficient control. The intelligent control is carried out using the complicated calculations made by either analog or micro-processing circuitry. Even though analog circuits have done well, they have made the digital controllers the first decision in latest developments in semi-conductor devices due to various their capabilities and cheap prices.

2. BACKGROUND OF POWER SYSTEM STABILITY

The stability is a significant for the stable and efficient operation of the energy system, limiting the transmission distance as well as the distribution capability of the power network is a deciding consideration. Consequently, different steps to enhance the stability of the system should be provided static and transient stability are part of the control angle stability. In consideration of the significance of PSS, Techniques of stability of the power system and steps to enhance the PSS are studied; In order to have improves overall to effective and stable power system operation [3]. In interconnected power systems, the majority of issues are related to lower frequencies fluctuation, particularly in the privatized model. Providing quick system damping as well as enhancing dynamic system efficiency.

In the last 3 decades, the traditional (PSS) function, i.e. a fixed function (lead-lag) compensator. PSS is commonly utilized to eliminate oscillation at low frequencies and increase system performance, as being the most economical regulation used for damping. PSS is presently being used by power providers worldwide to improve systems reliability as efficient controllers [4-15].While the electrical power damping features are fascinating, they adversely influence system voltage stability, others were attributable to PSS limited power, only local and not interarea oscillatory modes being damped. PSS could also lead to changes in the bus voltages during extreme disruptions, leading to power factor activity and a lack of stability and cannot avoid oscillation due to serious instability, Especially these three-phase faults that could occur in the terminal of generators [16]. In order to achieve greater stability margin, this condition has needed a revision of conventional energy systems principles and practices, Enhanced organizational stability and increased use of installed power networks. Almost all of the large power plants in various countries have so far been fitted with PSS [17-21].

The latest advancements in power electronics has contributed to FACTS development. FACTS instruments are among the latest proposals to mitigate these conditions by regulating the transmission lines and enhancing power fluctuations damping. It utilize of these controls improves operating stability by supplying power plant controllers with additional options. FACT begin designed to solve the shortcomings of existing mechanical operated power systems and improve the stability of the power system, with efficient and high-speed electronic equipment. In general, the FACTS systems are installed in the power system purpose of providing easy continuous monitoring of a power flow through the regulation of voltages to critical buses in the transmission system, by adjusting a transmission impedance or adjusting its phase angles between both the transmission line ends. A thorough analysis and examination of Information controllers is provided in this article. In This study shows an interest in this subject, where enhanced device reliability with FACTS devices has also been intensively researched. Besides that, damping control systems Versatile AC (FACTS) are alternate efficient methods, and also most research tend to be using them [22-25]. Most of these modern electronic equipment could be regulation all variables at the same time. In contrast to traditional devices which lack speed as well as controllability at simultaneous [26-30].

3. ANALYSIS OF FACT CONTROLLER SYSTEMS

This theory and advancement in the development of electronic circuits resulted in a new progression which is implemented by the Electric Power Research Institute (EPRI) in the end of 1980 and named Flexible AC transmission systems (FACTS). It has attracted considerable importance, Owing to recent developments in electronics that was a solution to a greater utilization of the already existing power systems services thus retaining and enhancing the safety of the power systems. In [31] a new idea was developed and a new direction was implemented in the study of power systems. The FACTS definition and its development were pioneered by Hingorani [32] in 1988. Edris among others in [33] suggested terminology and descriptions for various controllers of FACTS.

FACTS devices were used generally to resolve various steady state control issues of the power system. A lot of studies and analysis was carried out into the Damping of the Interarea and increased power system efficiency utilizing FACTS controls. In general, deploying FACTS equipment for the specific purpose of enhancing stability of the power system is not economically viable. FACTS devices get the ability to control the transmission of alternating current in a power system by increasing or reducing the current flow in particular lines thus reducing power management issues. The system depends on the ability to control a power flow route as well as the connecting of network links which are not totally interconnected. In general, this contributes to power trading among various stations. FACTS controller controllable and versatility make them ideal to minimize wind power intermittence-related issues. In addition, FACTS devices could supplied grids network services like the voltage regulation. FACTS devices can, injection or absorbs system reactive power as needed [34, 35]. Moreover, it stabilizes the Network and supports the transient stabilization of the system throughout electrical disturbances [36].

3.1. Classification of FACT Controller Systems Based on Technological Features

AC network controller could be divided into two kind's conventional network control and FACTS device, which are utilized for improving the power systems efficiency. Several of technology depend on switching: dynamically modified (such as phase shifting transformers), thyristor switched or fast switched, utilize IGBTs. However several kinds of FACTS are already understood and is utilized in power system, like the phase shifting transformer (PST) and the static VAR compensator (SVC). The FACTS technology spectrum was expanded by recent advances in electronic circuits and control.
The FACTS devices come with two separate classifications: according to technological characteristics,

- First generation: utilized gate-controlled ignition (SCR) thyristors.
- Second generation: gate operated semi-conductors (GTO's, IGCT IGBT's).

In addition, new FACTS technologies include intermittent green energy sources as well as growing international flow of electricity. The added versatility and controllability of the FACTS able the challenges of unreliable supply problems to be minimized. SVCs and STATCOM systems are ideally equipped for grid including faults rid that traditional wind turbines could not deliver. Fig. 1. Overview of traditional network controller and FACTS Controllers.

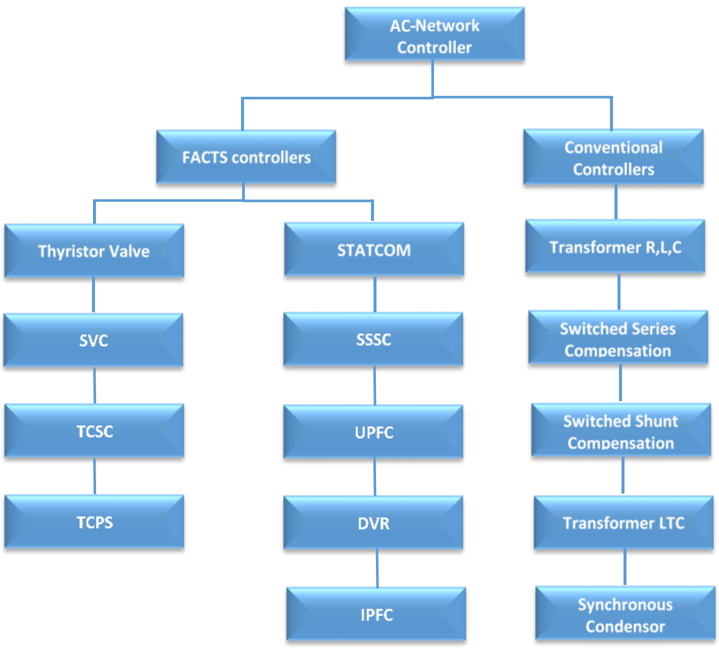

Figure 1. Overview of traditional network controller and FACTS Controllers.

In addition, FACTS eliminates grid fluctuations, which would be particularly interesting when working with it. Traditionally, Instruments such as a shunt-condenser, series-capacitor, and phase shift etc. These specifications have been utilized to control. Most of traditional systems can only handle one parameter simultaneously. FACTS devices allow one or more parameters to be managed at the same time. Several other

Facts devices like SSSC, UPFC and IPFC are able to regulate all three elements simultaneously.The main differentiation among the first and second generation systems is ability to produce reactive power and also to reciprocity active power. The FACTS instruments of first and second generation are classified following

3.1.1. First Generation of FACTS Controller

3.1.1.1. Static Var Compensator (SVC)

SVCs are member of the group of Flexible AC transmission system devices, voltage control and system stabilization. “Static" means that the SVC does not have moving elements. Before the SVC was invented, power factor reparations were the preserve of huge rotating equipment like a synchronous capacitors. A SVC is an automatic impedance-adaptive system, Conceived to get the unity of power factor closer to the device. The main objective is generally to regulate the voltage rapidly in a network at weaknesses points. Implementations may take place at the connectivity mid - point or even at the ends of the line.

(SVCs) using thyristor-switched capacitors (TSCs) as well as thyristor-controlled reactors (TCRs). The needed reactive power was built for providing or absorbing the energy [37, 38]. If a reactive load of the control system is capacitive which means (leading), Reactors can be used by SVC to absorb device VARs, Reducing device voltage. Under inductive (lagging) situations, the capacitor bank is automatically turned in, therefore providing greater voltage of the device. Ii could also be put close to heavy loads and the variable quickly, Arc furnaces, for example. SVC is equivalent to a synchronous, however without revolving, capacitor, it can be utilized for reactive power supply or absorption [39-41].

The SVC is associated with a transformer which is directly interconnection to a bus, where voltage of which is to be controlled. SVC consists of a shunt-reactor as well as a shunt-condenser which are controllable. Regulation of the overall sensitivity of SVC is achievable through the monitoring of a thyristor firing angle. SVC regulation has been suggested with genetic algorithms as well as Fuzzy-logic methods [42-48]. These techniques are preferable to traditional techniques through time-domain simulation results. SVC controls have been observed to have major effects on nonlinear system behavior, particularly when working under highly stressful environments and increasing SVC gains.

3.1.1.2. Thyristor-Controlled-Series-Capacitor (TCSC)

TCSC was used for several decades to enhance power transmission and to improve system reliability, and is among the most significant and well established FACTS instruments. TCSC is an efficient and economically viable way of addressing (transient issues, dynamic, steady state and voltage) stability in long-transmission-lines. The TCSC consists of 3 principal elements: condenser C, L inductor, SCR1 and SCR2 bi - directional thyristor. The combination of TCR as well as condenser makes for a smooth regulation of the capacitive reaction over a wide variety, and then switched over to a state in which the bi-direction thyristor couples continually perform and inject an inductive reactance into the line. TCSC can be understood by an interpretation of the behavior and attitude of an inductor that is attached to a fixed condenser in series. This operation could be designed as a quick switch from the corresponding system reactance’s [49, 50].

Chang and Chow] [51] have established TCSC’s optimum time control approach, with the minimum of a time-performance index. In [52] it was suggested to provide a fuzzy logic for a TCSC. The TCSC impedance was calibrated to a rotor angle of a unit as well as the extent of a velocity deviation. Additionally, various TCSC control systems, such as a changeable configuration controller, have been proposed [53, 54].

3.1.1.3. Thyristor-Controlled-Phase-Shifter (TCPS)

The TCPS is indeed a possible replacement for FACTS applications that have been recently suggested. In literature [55-59], the Researchers sophisticated numerous TCPS techniques. A phase shift angle shall be calculated as just a non - linear functions of rotor angle as well as velocity in a TCPS control technology. Even then, in a real-time framework with a huge number of generators, It is not really important to have a single generator rotor angle calculated in reference to the system [60].There has also been a significant emphasis on implementing different TCPS systems [61-63]. A non-linear synchronized generator stimulation as well as a TCPS regulator was suggested for enhanced power system transient stabilization. Furthermore, Because of his difficulty, the topic of modelling a multi-machine TCPS has also been dedicated to a few studies only [64].

Two separate TCPS systems are compared with Ise et al [65-67]. TCPS simulation and modelling were not taken into consideration as opposed to other FACTS systems. In linear- control technologies [68], the issue related to TCPS regulation were discussed. A basic control algorithm relies on the equivalent linear criteria was suggested by Edris [69]. That TCPS were modeled as just a nodes power injection, its results of which occur as extra injection of bus power in inner generator buses. Ngan [70] for form-B TCPS mentioned some other mathematical formula. In [71] the best ideal position of TCPS were identified by utilize of congestion control under regular and emergency situations. Jiang et al. [72] suggested a non-linear system function theory based on approach for the TCPS regulation.

3.1.2. Second Generation of FACTS Controller

3.1.2.1. Static Synchronous Compensator (STATCOM)

The STATCOM or Static Compensator is a shunt-connected component utilized on AC transmission systems as well as being a perfect replacement to standard VAR static compensation. It is part of a FACTS families of the second generation. The GTO thyristor-based STATCOM has enabled such technology it is suggested and promises stronger dampers properties than the SVC, since it shares active power transiently with system [73]. Because it is linked in parallel, it is named the shunt connected regulator. The STATCOM outlet current could be controlled automatically with no consideration to a system voltage, it is inductive or capacitive, regardless of the information. It typically supports voltage modulation as well as of lower power factor power network. While connecting to the source, it could provide dynamic stability as well as active AC control. However the voltage stability in the power system is quite frequently used [74].

The power storage device of STATCOM is presented in Fig 2.As seen in the fig device, the STATCOM Dc sides including power storage, which could be solar devices or condenser banks, are related. STATCOM often promises transient as well as dynamic stability for its energy storage device.

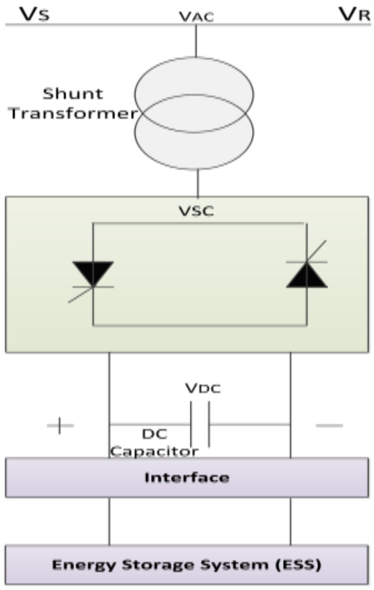

Figure 2. The power storage device of STATCOM

Haque [75] shows that STATCOM's ability and provide external damping of low frequency fluctuations by utilize of the power feature. In [76], STATCOM were found to be efficient in regulating the voltage of the power network. Abido [77] proposed an (SVD) focused on determining and calculating the controllability through separate control channels for the poorly damped electromechanical mode of STATCOM. The electromechanical were found to be regulated mostly by a phase modulation system. These were concluded that the damping stabilizers dependent on STATCOM increase the critical clearance time and substantially boost the transient reliability of the power system.

3.1.2.2. Static Synchronous Series Compensator (SSSC)

The SSSC is a modern series equipment's compensations of FACTS. Owing to its excellent capability over impedance compensation, the SSSC is increasingly important. It works in the same way as that of the STATCOM system. This has a voltage converter that is connecting by a transformer to a transmission line as seen in Fig 3. A continuous source of energy must be provided by the capacitor as well as the VSC's losses compensated. Under varying working conditions, its mode of operations, Parameters of regulation and control technique vary, And therefore relay safety will invariably be impacted.

For manage the active flow of power, SSSC is capable of inject voltage in quadrature with transmitting or receiving a line-end voltage. It does not absorb reactive power from the AC although this reactive power specification is created by providing a DC condenser itself. Which involves being able to control of both active as well as reactive power[78-80].moreover, If they require to balance the reactive power or preserve it, A comparatively limited source of electricity may be utilize to supply continuous voltage. If our objective is to control the infused voltage phase angle, only if the power source is large enough.

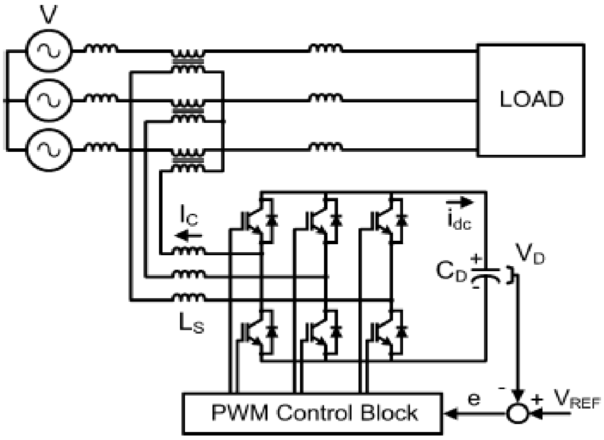

Figure 3. SSSC.

The SSSC was used to enhance performance of the system in several power system studies [81-83]. In [84] that SSSC were studied to regulate a line flow and increase the reliability of the power system. SSSC was implemented in various areas [85] In energy system studies like the optimum power flow, Fluctuation of dampers [86,87] and optimum position for stabilization power system [88,89]. Vinkovic [90] proposed a new process to designing an SSSC using the Newton-Raphson framework of power-flow computation. In required to formulate an SSSC-based controller, Panda proposed an evolutionary multi-objective configuration approach [91]. In order to prevent a torsional mode unrest in a series compensated transmission system, Hooshmand [92] was using an SSSC together with a constant condenser.

3.1.2.3. Dynamic Voltage Restorer (DVR)

DVR is a series attached FACTS device, for voltage control purposes especially over sensations load, it consisting of a VSC with such a d.c linked power storage. The VSC can be associated in series via a series-linked injection transformer as well as connection filters to the power network. A DVR is being utilized as a protective instrument against electrical disruption like voltage dips in sensitive equipment's as well as critical load. The active and reactive power needed to produce such voltages is provided by a VSC operated by a DC connection, as seen in Fig. 4 [93-95].

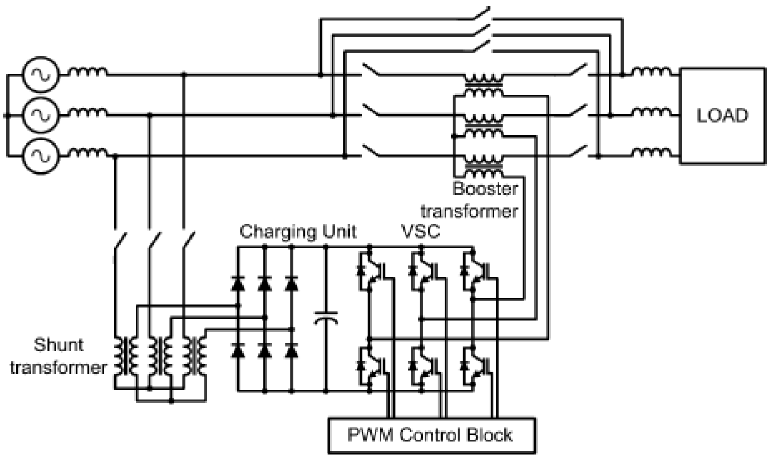

Figure 4. DVR.

The main elements of the DVR are:
- Switchgear;
- Booster transformer;
- Harmonic filter;
- IGCT VSC;
- DC charging unit.
- Regulate and protection system.
- Source of energy, A storage condenser bank

In two different modes, DVR operates, namely; Standby method as well as boost method, throughout the steady power system situation, A DVR in standby status would be precisely zero for the DVR voltage. Under this situation, the low voltage winding of the booster transformer is minimized through VSC, This triggers the independent converter legs to create a short-circuit path for the transformer association. Therefore, no switching of the semi-conductor. Even so, the DVR can turn to boost status upon failure detection (e.g. voltage inconstancies). The DVR voltage for this state is higher than zeros; thus, the booster transformer injects a compensatory voltage [96]. The DVR just implements a partial voltage amount. For instance, in the case of a voltage drop, The DVR respond rapidly by injects the required magnitude and phase angle voltage into the device. DVR does have a very fast response time of approximately 25 milliseconds [97]. In order to reduce the voltage drop, a rapid regulation response should be presented by the DVR. Furthermore, The DVR just produce conduction losses.

3.1.2.4. Unified Power Flow Controller (UPFC)

UPFC is one of the most popular and highly complicated as well as most adaptable FACTS device always utilized to boost power system operation [98].In 1991 Gyugi suggested the principle of UPFC. The three control parameters-the bus-voltage can be modified, transmission-line-reactance and phase-angle among two-buses, concurrently or separately

UPFC is dependent on a dc connection that works two inverters as illustrated in Fig 5.It is formed by two VSCs which are connected by a common dc connecting the coupled outputs, STATCOM as well as SSSC series, which supply a bi - directional flow of actual power [99]. Inverter 1, supplies or absorbs the actual power by the dc-connection that is linked by parallel connected transformer to the transmission line, next it has been converted Back to AC. Inverter 2 satisfies UPFC's main task, It injects AC voltage, that is attached parallel to the transmission line with such a manageable phase angle as well as magnitude [100,101]. Because of the typical dc connection there seem to be two terminals. AC terminal, in which inverter 2 generates reactive power and AC terminals with inverter 2 generating reactive power as well as DC terminal where actual power is substituted and transferred to dc.

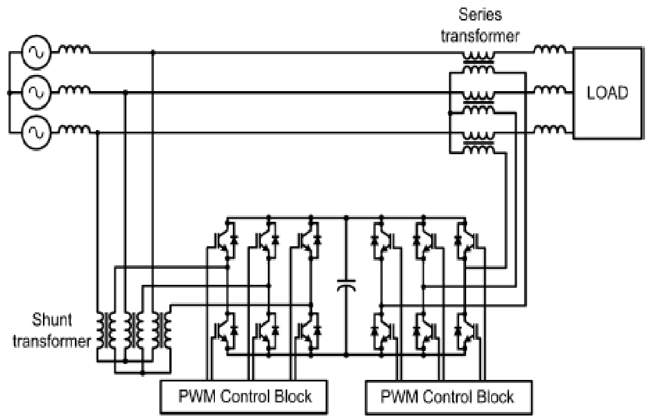

Figure 5. UPFC power circuit topology.

It has utilized mainly in the regulating transmission line power flow. Secondly, voltage regulation, enhancement of transient and dynamic stability. Furthermore, individual and simultaneous oscillation dampers as well as steady state stabilization could be achieved in an adaptive way [102,103], Provision of multi - function elasticity to address several of the energy industry challenges. The UPFC could regulate this within the context of conventional principles of power transmission, unlike other controls, it could be independently regulate the actual and the reactive power flow throughout the line.

3.1.2.5. Interline Power Flow Controller (IPFC)

The newest generation of FACTS instruments, called the IPFC, it is a combination of various series compensators systems that regulate power flows in transmission lines with considerable effectiveness. The latest compensation and efficient power flow control theory proposed by Gyugyi et al. [104] was utilized as the approach to the difficulties of compensating multiple power supply lines in a power substation. In other words, several VSCs are connected to a specific DC terminal in IPFC as well as all series compensation is required for each transmission line. The power optimization could be a performed of an entire transmission system by means of sufficient power wheeling from overloaded transmission lines with under loaded power lines by mutual DC connects [7]. As seen in Fig 6, a simple IPFC includes two VSCs.

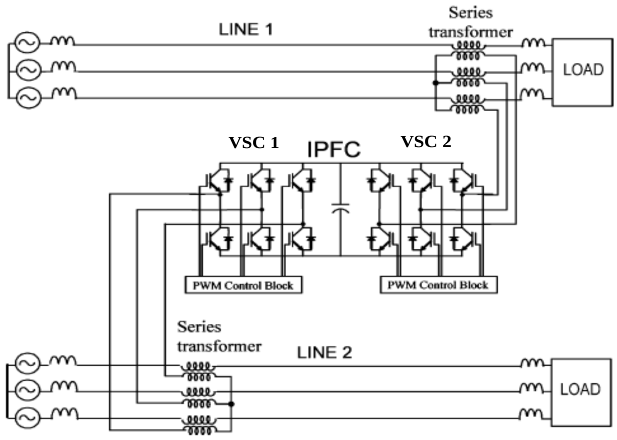

Figure 6. IPFC power circuit topology.

Every inverter inject voltage of the series for transmission line compensation as well as the mutual DC connection can be established utilizing the bi-directional relation between the two voltage supply for real power transmission[[105]. Consequently, IPFC is similar to UPFC power flow regulation. Just one change in IPFC is whether inverter 1's active power is replaced by inverter 2's additional sequence using an additional line rather than a UPFC shunt inverter [31, 5] .The IPFC is in regulatory modes when it performs less than its rating power, the regulatory lowering with one side of a P and Q then on the other side of a P. Furthermore, the total active power generated from two VSCs is 0, which neglects energy loss.

3.2. Advantages of FACT Controller Systems

- FACTS controllers provide the following benefits [106,107]:
- Performance and reliability improved transmission system
- Increased reliability of the complex and intermittent grid and elimination of loop flows
- Mitigate sub-synchronous resonance (SSR)
- Load compensation
- Environmental benefits Better usage of existing transmission framework resources
- Power quality improvement
- Greater transmission potential between managed areas
- Damping of power system oscillation
- Limit short circuit currents
- Improved supply efficiency for sensitive industries
- Better use of existing infrastructure for transmission
- Enhance the transient stability limitation for the device
- Rising the load capacity of the system
- Enhance system damping
- Prevention of cascading outages
- Power control enhancement

3.3. Connection Type of FACT Controller Systems

FACTS controllers are categorized based on the kinds of power network connection [108-111]:

3.3.1 Serial Controllers

These FACTS devices are operate by inject a serial impedance. Practically a series controller could comprise of a fundamental frequency or variable impedance source dependent on variable circuitry including a condenser or reactor. In theory, each series controls inject the voltage into series with the line. A serial controller provides either reactive power or absorbs it; therefore, every other phase angle is active power control only. Members of this kind of device comprise SSSC, TSSC, TCSC, IPFC and TCSR.

3.3.2 Derivation Controllers

Derivation controls operate through injecting current into device only at interconnecting stage in a quadrature with line. Typically, they compose of an electronic changeable, a changeable impedance, or even both. The changeable impedance connecting to the line voltage induces changeable flow of current, representing the injecting of the current into line. The device absorbs just reactive power; any other phase angle reflects control of active power. The control systems which belong to this group involve STATCOM, TSC, TCR, and TCBR.

3.3.3 Serial To Serial Controllers

FACTS system is a combination of two different series FACTS which is a combination (series-series), that are coordinately regulated, or may have been a single controller, in a multi-line transmission system. Series controllers supplied reactive independent series compensation for every line as well as actual power over the power connection between the lines. The actual power transition for the consolidated (series - series) control system, which is called Inter-Line-Power-Flow-Controller, allows both the actual as well as the reactive power flow to be balanced in the lines, optimizing transmission system usage; The word "unified" in this situation implies that each the controllers' DC terminals are connected to accomplish successful power transfers among them.

3.3.4 Serial-Derivation Controllers

this Type of FACT connection systems could be a mixture of serial as well as derivation control, The device normally uses combination shunt and series controllers, which insert current into the device regulates the shunt element of the controller, whereas the voltage in series takes charge of the power in line with its series element. Therefore, a shunt as well as the series element of the controllers are united, at any situation, a proper interchange is possible to implement an actual power transfer among the series and shunt controller. Unified Power Flow Controller (UPFC) is indeed an ideal device, that integrating feature of a filters as well as conditioning is becoming a Universal Power Line Conditioner (UPLC).

4. ANALYSIS OF STABILITY

Stability analyses are categorized into three groups based on the extent and order of severity of the disruption. Fig. 7. Shows the classification of power system analysis [112-117].

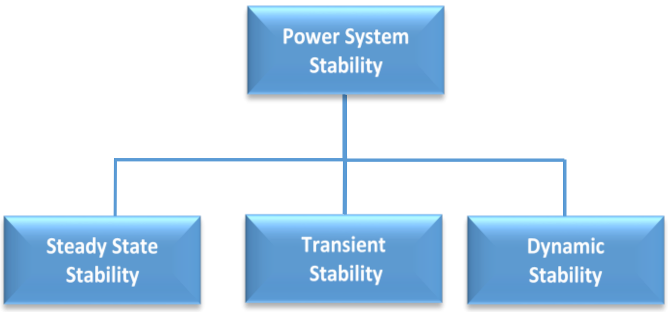

Figure 7. The classification of power system analysis

4.1. Stability with steady state

Because the electrical system is often subject to minor disruptions, the system needs steady state reliability to run properly. The control system is able to restore synchronist, after sluggish and tiny disturbances. In addition, steady-state-stability in stable conditions is related to the response to a progressively rising load of a synchronous machine. Essentially, the top limit of system loading is calculated without compromising synchronicity, As long as the loading progressively increases.

evaluation of stable state stability may be needed, In the preparation of electric power system analysis and synthesis, That power therefore generated via the generator (G) and motor (M) which is applied with equations (1) and (2) respectively.

$$P_G = \frac{D}{B} VG^2 \cos(\beta - \Delta) - \frac{VGVM}{B} \cos(\beta + \delta) \quad (1)$$

$$P_M = \frac{VGVM}{B} \cos(\beta - \delta) - \frac{A}{B} VM^2 \cos(\beta - \alpha) \quad (2)$$

4.2. Stability with transient

Transient stability is a control system’s capability to remain synchronized when exposed unexpected for major disrupted. This can induce very significant differences in rotational speed, power angles as well as power transfers. Typically occurring within a short period such as one second with a generator that is near to the source of disruption, such as a malfunction in transmission facilities, Loss of production or loss of heavy load. A rapid, broad perturbation involves breakdown applications, fault clearance, switching (on / off) the system components (transmission line - transformer - generator loads). Transient stability studies aim to assess if the system remains in stability despite these shocks or not. If it is noticed that the machine remains basically in synchronism with first, second, the system is considered to still be transiently stable.

Transient stability study includes several of the mechanical characteristics of the devices in the system. Following each disturbance, In order to satisfy the necessity of the power transmission concerned, the devices should change the relative angles of their rotors. Transient stability limits are nearly often lesser than steady state rate and thus are very essential. The transient stability limit count on the kind of perturbation, position and volume of the disturbances. Stability of energy systems specifically relates to the study of rotor stability. Different assumptions required for this are:

- for stability analysis, A stabilized three-phase system including equilibrated disturbance were regarded
- Deviations of machine frequencies from synchronous frequency are minimal.
- The DC offset as well as the high frequency current are available in the short- circuit in the generator. However, these are ignored to evaluate the equilibrium.
- The load of the network as well as impedance is steady state condition. Therefore the power flow equation will determine voltages, currents as well as power.

4.3. Stability in Dynamic

Dynamic stability is the power system's capability to stay in synchronized following the first swing (transient stability duration), till a new stable balance status has been achieved. Moreover, it is utilized in the analysis of transient power systems situations. Electrical disruptions in a power grid can lead to transient electromechanical operations. In addition to the transient electrical phenomenon, generating unit's power balance is often disturbed as well as the mechanical fluctuation of engine rotors is also accompanied by the disturbances.

This minor disturbances happen because of indiscriminate loading as well as generation rates. The indiscriminate differences could result in catastrophic failure in an interconnected power system, because it might proceed to a steady rise throughout the rotor angle. Following the disturbance, primary mover responds to raise or decrease energy demand to restore a balance among power inputs as well as exciting electricity loads. Dynamic stability means a response to minor fluctuations happening mostly on the system, producing fluctuation. When these fluctuations may not achieve more than some amplitudes and die out readily, the process is seen to be dynamically stable. When these fluctuations continue to rise in amplitude, that process is dynamically un-stable. This kind of instability typically comes through a connectivity among control systems.

5. ANALYSIS OF ENHANCEMENT FOR PSS BASED FACTS CONTROLLERS

One of the best achievements of technology in those years is FACTS controllers. Various FACTS devices are being utilized for optimizing control and enhance the ability of power transmission. Thyristor regulated FACTS devices, like the TCSC as well as SVC, are modelled on the transmission system in load flow experiments as impedance controlled devices [118-121]. Nevertheless, VSC-based controllers like SSSC as well as IPFC, controllers as STATCOM and the combination of both; shunt as well as VSC dependent on controllers, The UPFC is much more complicated and is constructed as just a source manageable system [122-125]. The Interline Power Flow Controller (IPFC) is indeed equally close yet cost-effective to that of Unified Power Flow Controller (UPFC) UPFC. FACTS technical support for finding solutions such as transient and dynamic stability, In Fig 8 below is shown the practical benefits of core FACT techniques

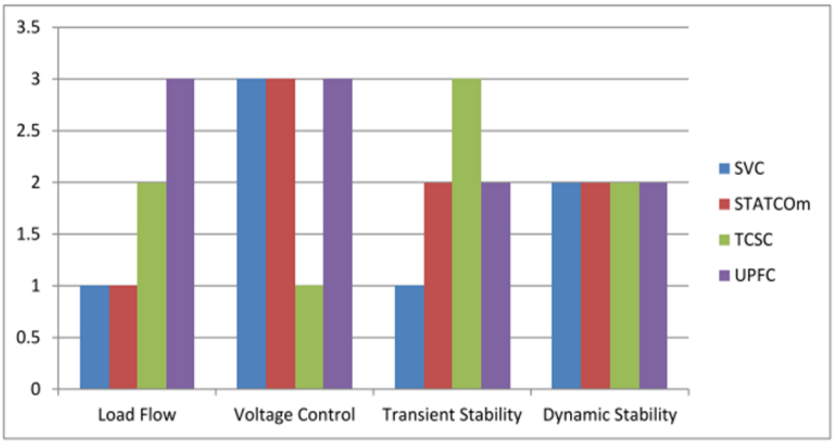

Fig. 8. Practical benefits of core FACT techniques

The technological advantages of FACTS in solving transient stability challenges for dynamic implementation; Damping, regulation of voltage after contingency as well as stabilization of voltage are outlined. If the complex (rapidly changing) network requirements must be met, FACTS techniques are mostly needed. The interrelationship between voltage, current, impedance, control as well as reactive power, many characteristics for each device. The control parameters for different FACTS controllers are mentioned in Table 1 [126,127].

Table 1. The control parameters for different FACTS controllers

N.o	FACTS controllers	Technical contribution
1.	Static synchronous Compensator (STATCOM)	Voltage control, VAR compensation, Transient and dynamic Stability, Voltage stability, Damping oscillations
2.	Static VAR Compensator (SVC,TSC,TCR)	Voltage control, VAR compensation, Transient and dynamic, Stability, Voltage stability, Damping oscillations
3.	Static synchronous series Compensator (SSSC)	current control, Transient and dynamic, Stability, Voltage stability, Damping oscillations
4.	Thyristor Controlled series Compensator (TCSC/TSSC)	current control, Transient and dynamic, Stability, Voltage stability, Damping oscillations
5.	Unified power flow controller (UPFC)	Active and reactive power control, Voltage control, VAR compensation, Transient and dynamic , Stability, Voltage stability, Damping oscillations
6.	Interline power flow controller (IPFC)	Voltage control, Reactive power control, Transient and dynamic, Stability, Voltage stability, Damping oscillations
7.	Amalgam power flow controller (APFC)	Controls power flow in a network but also increases the reliability and security of power systems.

Table 2. The FACTS controllers function for power system operation [128].

Subject	Issues	Corrective Action	FACTS Devices
Voltage limits	Low voltage at heavy load	Supply reactive power	SVC, STATCOM
	High voltage at low load	Reduce line reactance	TCSC
	High voltage following an outage	Absorb reactive power	SVC, STATCOM
	Low voltage following at outage	Absorb reactive power, prevent overload	SVC, STATCOM
		Supply reactive power, prevent overload	SVC, STATCOM
Thermal limits	Transmission circuit overload	Increase transmission capacity	TCSC, SSSC, UPFC
Load flow	Power distribution on parallel lines	Adjust line reactance	TCSC, UPFC
	Load flow reversal	Adjust phase angle	UPFC, SSSC, PAR
		Adjust phase angle	UPFC, SSSC, PAR
Short circuit power	High short circuit current	Limitation of short circuit current	TCSC, UPFC
Stability	Limited transmission power	Decrease line impedance	TCSC, UPFC

Table 3 shows that the SSSC needs additional time to improve stability. UPFC's and TCSC FACTS unit is indeed a powerful instrument to increase inter-area power system load transfer, voltage regulation and stabilization [49,104].

Table 3. Comparison of Power System Stability Improvement FACTS Instruments

No.	FACTS Device	Power System Stability Improvement	Settling time in post fault period (in seconds)
1.	UPFC	YES	0.6
2.	TCSC	YES	1.5
3.	SVC	YES	7
4.	SSSC	YES	11

The traditional solutions are usually cheaper than FACTS controller, however their dynamic performance is minimal. The designers have the challenge of finding the cheapest option. Table 4 displays the average cost per KVAR of different traditional instruments as well as FACTS devices. Nevertheless, the price per KVAR reduction when the greater capacity of FACTS devices. The total price therefore based on the size of a fixed as well as regulated component of the FACTS devices. The price of FACTS facilities constitutes just half of the actual price of a FACTS project. Such expenses such as civil works, installation, commissioning, insurance, as well as administration and management which is around half of a FACTS project price.

Table 4. The traditional FACTS Devices and its costs

FACTS Controllers	Cost(US $)
Shunt Capacitor	8/kVar
Series capacitor	20/kVar
SVC	40/kVar controlled portions
TCSC	40/kVar controlled portions
STATCOM	50/kVar
UPFC Series Portions	50/kVar through power
UPFC Shunt Portions	50/kVar controlled

6. CONCLUSION

According to above clarification of some strength conditions, power point outline and short out conditions, if the shortcoming endures, the heap point will increment inconclusively in light of the fact that the information force will be completely utilized for increasing speed. This may prompt a flimsy condition. The essential highlights of FACTS regulators and their capacity to improve structure security are the essential worry of a force casing's feasible monetary activity. The territory and money signals utilized for the FACTS-based damping regulators plan has been discussed. The issue of coordination between the different control plans was additionally thought of. Execution check was investigated for a few FACTS regulators. Possible future pathway for FACTS development was analyzed. Besides, the experience of huge genuine offices and organizations and advances in semiconductor development has been abbreviated. A concise review of FACTS applications is appeared for ideal force stream and unstructured energy publicizing.

REFERENCES

[1] B. Qi, “Identification of Influential Parameters Affecting Power System Voltage and Angular Stability Analysis,” 2019.

[2] T. Jaimol and J. Tibin B. Anna, "Analysis of Voltage Collapse in the Kerala Power Grids Using SVC, UPFC & SSSC," in International Multi-Conference on Automation, Computing, Communication, Control and Compressed Sensing (iMac4s), 22-23 March 2013.

[3] D. Xie, D. Zang, and P. Gao, “Research on Stability of the Power System,” IOP Conf. Ser. Earth Environ. Sci., vol. 81, no. 1, 2017.

[4] Y. I. Al Mashhadany, Optimal Writing For Research Article In Engineering Journals, Solid State Technology journal, Vol.63 Iss.6, 2020, pp: 14020-14036

[5] F. deMello and C. Concordia, “Concepts of Synchronous Machine Stability as Affected by Excitation Control”, IEEE Trans. PAS, 88(1969), pp. 316–329.

[6] P. W. Sauer and M. A. Pai, Power System Dynamics and Stability. Prentice Hall, 1998.

[7] J. R. Smith, G. Andersson, and C. W. Taylor, “Annotated Bibliography on Power System Stability Controls: 1986- 1994”, IEEE Trans. on PWRS, 11(2)(1996), pp. 794–800.

[8] B. Stott, “Power System Dynamic Response Calculations”, Proc. IEEE, 67(1979), pp. 219–241.

[9] E. Larsen and D. Swann, “Applying Power System Stabilizers”, IEEE Trans. PAS, 100(6)(1981), pp. 3017–3046.

[10] G. T. Tse and S. K. Tso, “Refinement of Conventional PSS Design in Multimachine System by Modal Analysis”, IEEE Trans. PWRS, 8(2)(1993), pp. 598–605.

[11] Y.I. Al Mashhadany, Design and Analysis of 7-DOF Human-Link Manipulator Based on Hybrid Intelligent Controller, SPIIRAS Proceedings. 2020. Vol. 19 No. 4, pp: 774-802, DOI 10.15622/sp.2020.19.4.3

[12] B. G. Rogers, Power Systems Oscillations. Boston: Kluwer Academic Press, 1999.

[13] IEEE Symposium on Eigenanalysis and Frequency Domain Methods for System Dynamic Performance. IEEE Publication No. 90TH0292-3-PWR, 1989.

[14] IEEE Symposium on Inter-Area Oscillations in Power Systems. IEEE Publication No. 95TP101, 1994.

[15] J. Paserba, Analysis and Control of Power System Oscillations. CIGRE Final Report, Task Force 07, Advisory Group 01, Study Committee 38, 1996.

[16] A. H. M. A. Rahim and S. G. A. Nassimi, “Synchronous Generator Damping Enhancement through Coordinated Control of Exciter and SVC”, IEE Proc. Genet. Transm. Distrib., 143(2)(1996), pp. 211–218.

[17] Kundur P., Klein M., Rogers G., Zywno M., Application of power system stabilizers for enhancement of overall system stability. IEEE Trans. Power Syst., 4 (2002) No. 2, 614-626.

[18] Eslami M., Shareef H., Mohamed A., Tuning of power system stabilizers using particle swarm optimization with passive congregation. Inter. J. Phys. Sci.,17(2010) No. 5, 2658–2663

[19] Eslami M., Shareef H., Mohamed A., power system stabilizer design using hybrid multi-objective particle swarm optimization with chaotic. J. Cent. South Univ. Technol.,18(2011) No. 5, 1579-1588

[20] Eslami M., Shareef H., Mohamed A., Khajehzadeh m., Damping of Power System Oscillations Using Genetic Algorithm and Particle Swarm Optimization. Inter. Rev. Electr. Eng., 6(2010) No.5, 2745-2753.

[21] Eslami M., Shareef H., Mohamed A., Application of Artificial Intelligent Techniques in PSS design: A survey of the state-ofthe- art methods. Przegląd Elektrotechniczny (Electr. Rev.) 87(2011) No. 4. 188-197.

[22] Eslami M., Shareef H., Mohamed A., Application of PSS and FACTS devices for intensification of power stability. Inter. Rev. Electr. Eng., 5 (2010) No. 2, 552-570.

[23] Hingorani N., High Power Electronics and flexible AC Transmission System, IEEE Power Eng. Rev., 8 (1988) No. 7, 3 4.

[24] A. R. Bhowmik and C. Nandi, "Implementation of Unified Power Flow Controller (UPFC) for Power Quality Improvement in IEEE 14-Bus System," International Journal of Computer Technology and Applications, vol. 2, no. 6, pp. 1889-1896, 2011.
[25] T. Sýkora, J. Švec, and J. Tlustý, Z. Müller, "Dynamic Loading Control Using FACTS in Extraordinary States," in In Proceedings of the 12th International Scientific Conference Electric Power Engineering 2011, Ostrava, 2011, pp. 1-4.
[26] A. Garg and S. K. Agarwal, "Modeling and Simulation of SVC Controller for Enhancement of Power System Stability," International Journal of Advances in Engineering & Technology, vol. 1, no. 3, pp. 79-84, July 2011.
[27] V. Vahidinasab and A. Mosallanejad A. Kazemi, "Study of STATCOM and UPFC Controllers for Voltage Stability Evaluated by Saddle-Node Bifurcation Analysis," in First International Power and Energy Conference PEC, Putrajaya, Malaysia., November 28-29, 2006, pp. 191-195.
[28] Manoj Nair, "EHV AC & DC TRANSMISSION," in EHV AC & DC TRANSMISSION, 2nd ed. Bhopal:, India: Balaji Learning Books, 2010, pp. 161-162.
[29] S. Jamhoria and L. Srivastava, "Applications of Thyristor Controlled Series," in International Conference on Power, Signals, Controls and Computation (EPSCICON), 2014.
[30] A. K. Mohanty and A. K. Barik, "Power System Stability Improvement Using FACTS Devices," International Journal of Modern Engineering Research (IJMER), vol. 1, no. 2, p. 666 672, 2013.
[31] Hingorani N.G., FACTS technology and opportunities, lEE Colloquium on Flexible AC Transmission Systems-The Key to Increased Utilisation of Power Systems, 1994,401-410
[32] Hingorani N.G., Future role of power electronics in power systems, International Symposium on Power Semiconductor Devices and ICs, 1995 13 -15
[33] Edris A.,"Proposed Terms and Definitions for Flexible AC Transmission System, IEEE Trans. Power Deliv., 12 (1997), No.4, 1848–1852.
[34] S. Akter, A. Saha, P. Das, "Modeling, Simulation and Comparison of Various FACTS Devices in Power System", International Journal of Engineering Research and Technology, Volume-1, Issue-8, October 2012, pp. 1-12
[35] P. Srivastava and R. Pardhi, "A Review on Power System Stability and Applications of FACT Devices," vol. 3, no. 3, pp. 879–883, 2013.
[36] O. Nourelden, "Low Voltage Ride Through Strategies for SCIG Wind Turbines Interconnected Grid", International Journal of Electrical and Computer Sciences, Volume-11, No.-2, pp. 59 -65, 2013
[37] Canadian Electrical Association, "Static compensators for reactive power control," 1984.
[38] Y. I. Al Mashhadany, W. M. Jasim,Real time modified programmable universal machine for assembly (PUMA) 560 with intelligent controller Indonesian Journal of Electrical Engineering and Computer Science Vol. 20, No. 3, December 2020, pp. 1194-1202, DOI: 10.11591/ijeecs.v20.i3.
[39] A. Sode-Yome, N. Mithulananthan, Kwang Y. Lee, "A Comprehensive Comparison of FACTS Devices for Enhancing Static Voltage Stability" 1- 4244-1298-6/07, 2007, IEEE.
[40] D. Murali, Dr. M. Rajaram, N. Reka, "Comparison of FACTS Devices for Power System Stability Enhancement "International Journal of Computer Applications (0975 – 8887) Volume 8– No.4, October 2010.
[41] Wang H. F., Swift F. J., A Unified Model for the Analysis of FACTS Devices in Damping Power System Oscillations. Part I: Single-Machine Infinite-Bus Power Systems, IEEE Trans. PWRS, 12(1997) no. 2, 941–946.
[42] P. Ju, E. Handschin, and F. Reyer, "Genetic Algorithm Aided Controller Design with Application to SVC", IEE Proc. Genet. Transm. Distrib., 143(3)(1996), pp. 258–262.
[43] P. K. Dash, S. Mishra, and A. C. Liew, "Fuzzy-Logic Based VAR Stabilizer for Power System Control", IEE Proc. Genet. Transm. Distrib., 142(6)(1995), pp. 618–624.
[44] G. El-Saady, M. Z. El-Sadek, and M. Abo-El-Saud, "Fuzzy Adaptive Model Reference Approach-Based Power System Static VAR Stabilizer", Electric Power Systems Research, 45(1)(1998), pp. 1–11.
[45] C. S. Chang and Y. Qizhi, "Fuzzy Bang–Bang Control of Static VAR Compensators for Damping System-Wide Low-Frequency Oscillations", Electric Power Systems Research, 49(1999), pp. 45–54.
[46] Qun Gu, A. Pandey, and S. K. Starrett, "Fuzzy Logic Control for SVC Compensator to Control System Damping Using Global Signal", Electric Power Systems Research, 67(1)(2003), pp. 115–122.
[47] K. L. Lo and M. O. Sadegh, "Systematic Method for the Design of a Full-scale Fuzzy PID Controller for SVC to Control Power System Stability", IEE Proc. Genet. Transm. Distrib., 150(3)(2003), pp. 297–304.
[48] J. Lu, M. H. Nehrir, and D. A. Pierre, "A Fuzzy Logic-Based Adaptive Damping Controller for Static VAR Compensator", Electric Power Systems Research, 68(1)(2004), pp. 113–118.
[49] Mehrdad Ahmadi Kamarposhti, Mostafa Alinezhad, Hamid Lesani, Nemat Talebi, "Comparison of SVC, STATCOM, TCSC, and UPFC Controllers for Static Voltage Stability Evaluated by Continuation Power Flow Method" 978-1-4244-2895-3/2008 IEEE Electrical Power & Energy Conference.
[50] D. Murali, Dr. M. Rajaram, N. Reka, "Comparison of FACTS Devices for Power System Stability Enhancement "International Journal of Computer Applications
[51] L. Gyugyi, R. Otto, and T. Putman, "Principles and applications of static, thyristor-controlled shunt compensators," IEEE Trans. Power App. Syst., vol. PAS-97, no. 5, pp. 1935–1945, Oct. 1980.
[52] T. Lie, G. Shrestha, and A. Ghosh, "Design and Application of Fuzzy Logic Control Scheme for Transient Stability Enhancement in Power Systems", Electric Power Systems Research, 1995, pp. 17–23.
[53] Y. Wang, R. Mohler, R. Spee, and W. Mittelstadt, "Variable Structure FACTS Controllers for Power System Transient Stability", IEEE Trans. PWRS, 7(1992), pp. 307–313.
[54] T. Luor and Y. Hsu, "Design of an Output Feedback Variable Structure Thyristor Controlled Series Compensator for Improving Power System Stability", Electric Power Systems Research, 47, 1998, pp. 71–77.

[55] A.A. Hashmani, W. Youyi and T. Lie, Design and application of a nonlinear coordinated excitation and TCPS controller in power systems, American Control Conference, 2001, 811-816
[56] Y. Wang, A. A. Hashmani, and T. T. Lie, "Nonlinear co- ordinated excitation and TCPS controller for multimachine power system transient stability enhancement," IEE Proceedings: Generation, Transmission and Distribution, vol. 148, 133 141, 2001.
[57] R. J. Abraham, D. Das, and A. Patra, "Effect of TCPS on oscillations in tie-power and area frequencies in an interconnected hydrothermal power system," IET Generation, Transmission and Distribution, vol. 1, 632-639, 2007.
[58] S. Robak, D. D. Rasolomampionona, and M. Januszewski, "Damping of power swings using a FACTS device of the TCPS type: Modelling and laboratory experiments," Int. J. Electr. Eng. Edu., vol. 44, 263-279, 2007
[59] R. J. Abraham, D. Das, and A. Patra, "AGC study of a hydrothermal system with SMES and TCPS," European Transactions on Electrical Power, vol. 19, 487-498, 2009.
[60] M. Hoseynpoor, M. Najafi, R. Ebrahimi, and M. Davoodi, "Power system stability improvement using comprehensive FACTS devices," *Int. Rev. Model. Simulations*, vol. 4, no. 4, pp. 1660–1665, 2011.
[61] R. M. Mathur and R. S. Basati, "A Thyristor Controlled Static Phase Shifter for AC Power
[62] Transmission", IEEE Trans. PAS, 100(5)(1981), pp. 2650–2655.
[63] M. Iravani and D. Maratukulam, "Review of Semiconductor-Controlled (Static) Phase Shifters for Power System Applications", IEEE Trans. PWRS, 9(4)(1994), pp. 1833–1839.
[64] R. Baker, G. Guth, W. Egli, and O. Eglin, "Control Algorithm for a Static Phase Shifting Transformer to Enhance Transient and Dynamic Stability of Large Power Systems", IEEE Trans. PAS, 101(9)(1982), pp. 3532–3542.
[65] A. Ishigane, J. Zhao and T. Taniguchi, Representation and control of high speed phase shifter for an electric power system, lEE Proceedings Generation Transmission and Distribution, 145 (1998), No.3, 308- 314.
[66] V. Rajkumar and R. Mohler, "Bilinear Generalized Predictive Control Using the Thyristor Controlled Series Capacitor", IEEE Trans. PWRS, 9(4)(1994), pp. 1987–1993.
[67] Q. Zhao and J. Jiang, "A TCSC Damping Controller Using Robust Control Theory", Int. J. of Electrical Power & Energy Systems, 20(1)(1998), pp. 25–33.
[68] Ise T., Hayashi T., Ishii L., Kumagai S., Power system stabilizing control using high speed phase shifter, Proceedings of the Power Conversion, 1997, 735-740
[69] P.L. So, D.C. MacDonald, Stabilization of inter-area modes by controllable phase shifter, IEEE AFRICON, 1996, 419 -424.
[70] Yousif I. Al Mashhadany, and Hussain A. Attia. "Novel Design and Implementation of Portable Charger through Low-Power PV Energy System." Advanced Materials Research, vol. 925, Trans Tech Publications, Ltd., Apr. 2014, pp. 495–499. Crossref, doi:10.4028/www.scientific.net/amr.925.495.
[71] H.W. Ngan, modelling static phase shifters in multi-machine power systems, International Conference on Advances in Power System Control, 1997, 785 -790
[72] Kazemi and R. Sharifi, "Optimal location of thyristor controlled phase shifter in restructured power systems by congestion management,"IEEE International Conference on Industrial Technology, Mumbai, 2006, 294-298.
[73] N. I. A. Wahab, A. Mohamed, A. Hussain, "Fast transient stability assessment of large power system using probabilistic neural network with feature reduction techniques, Expert System With Applications", 2011, 38(9):11112-11119.
[74] D. J. Hanson, M. L. Woodhouse, C. Horwill, D. R. Monkhouse, and M. M. Osborne, "STATCOM: A New Era of Reactive Compensation", Power Engineering Journal, June 2002, pp. 151–160.
[75] Z. Muller, J. Svec and J. Tlusty J. E. Essilfie, "STATCOM Effect on Voltage Stability in Ghanaian Electrical Grid," in 15th International Scientific Conference on Electric Power Engineering (EPE), Proccedings of the 2014, Brno, 12-14 May, 2014, pp. 235 – 240.
[76] M. H. Haque, "Use of Energy Function to Evaluate the Additional damping Provided by a STATCOM", Electr.Power Syst. Res, 72(2)(2004), 195–202.
[77] H. Wang, H. Li, and H. Chen, "Application of Cell Immune Response Modelling to Power System Voltage Control by STATCOM", IEE Proc.-Gener. Transmi. Distib., 149(2002), 102–107.
[78] M. A. Abido, "Analysis and Assessment of STATCOM-Based Damping Stabilizers for Power System Stability Enhancement", Electr. Power Syst. Res., 73 (2005), 177–185.
[79] S. S. Rangarajan, M. Ambili, P. Sujyothi and V. G. Nithya S. Sreejith, "Enhancing The Power Transfer Capability In A Power System Network Using Series Connected Facts Devices For Increased Renewable Penetration," in International Conference on Advances in Electrical Engineering (ICAEE), Vellore, Jan. 2014, pp. 1 – 6.
[80] T. Nguyen and C.T. Vu, "Complex-Variable Newton-Raphson Load- Flow Analysis with FACTS Devices," in IEEE Transmission and Distribution Conference and Exhibition, 2006, pp. 183 – 190.
[81] Y. H. Song and Y. Z. Sun Y. Xiao, "Power flow control approach to power systems with embedded FACTS devices," IEEE Trans on Power Systems, vol. 17, no. 4, November 2002.
[82] Xiao-Ping Zhang, "Advanced modeling of the Multicontrol Functional Static Synchronous Series Compensator (SSSC) in Newton Power Flow", IEEE Trans. on PWRS, 18(4)(2003), 1410–1416.
[83] I. Ngamroo and W. Kongprawechnon, "A Robust Controller Design of SSSC for Stabilization of Frequency Oscillations in Interconnected Power Systems", Electr.Power Syst. Res, 67(2)(2003), 161–176.
[84] G. N. Pillai, A. Ghosh, and A. Joshi, "Torsional Interaction Between an SSSC and a PSS in a Series Compensated Power System", IEE Proc.-Gener. Transmi. Distib., 149(6)(2002), 653–658.
[85] N. I. A. Wahab and A. Mohamed, "Area-Based COI-Referred Rotor Angle Index for Transient Stability Assessment and Control of Power Systems", Abstract and Applied Analysis, 2012, 410461.

[86] P. Kumkratug and M. H. Haque, “Improvement of Stability Region and damping of a Power System by Using SSSC”, IEEE Power Engineering Society General Meeting, 2003, vol. 3, 1417–1421.

[87] Shakarami, MR; Kazemi, A: “Evaluation of Different Options for SSSC-Based Stabilizer to Improve Damping Inter-Area Oscillations in a Multi-Machine Power System”, Int. Rev. Electr. Eng., vol. 4 n. 6, 1336-1346, 2009

[88] F. Al-Jowder, "Improvement of synchronizing power and damping power by means of SSSC and STATCOM," Elect. Power Syst..Res.,77(2007), 1112-1117.

[89] M. H. Haque, "Use of SSSC to improve first swing stability limit and damping of a power system," Australian Journal of Electrical and Electronics Engineering, vol. 3, 17-26, 2006.

[90] M. El Moursi, A. M. Sharaf, and K. El-Arroudi, "Optimal control schemes for SSSC for dynamic series compensation," Electr.Power Syst. Res, vol. 78, 646-656, 2008.

[91] A.Kazemi, M. Ladjevardi, and M. A. S. Masoum, "Optimal selection of SSSC based damping controller parameters for improving power system dynamic stability using genetic algorithm," Iran. J. Sci.Tech., vol. 29, 1-10, 2005.

[92] A.Vinkovic and R. Mihalic, "A current-based model of the static synchronous series compensator(SSSC) for Newton- Raphson power flow," Electr.Power Syst. Res, vol. 78, 1806- 1813, 2008.

[93] S. Panda, "Multi-objective evolutionary algorithm for SSSCbased controller design," Electr.Power Syst. Res, vol. 79, 937- 944, 2009.

[94] R. Hooshmand and M. Azimi, "Investigation of dynamic instability of torsional modes in power system compensated by SSSC and fixed capacitor," Int. Rev. Electr. Eng., vol. 4, 129- 138, 2009.

[95] N. A. M. Kamari, I. Musirin, A. A. Ibrahim, S. A. Halim, “Intelligent swarm-based optimization technique for oscillatory stability assessment in power system”, IAES International Journal of Artificial Intelligence, 2019, 328-337.

[96] Y. A. Ahmed, Y. I. Al Mashhadany , M.A. Nayyef, High Performance of Excitation System for Synchronous Generator based on Modeling Analysis, Bulletin of Electrical Engineering and Informatics; Vol. 9, No. 6, December 2020, pp. 2235-2243

[97] T. K. Saha and P. T. Nguyen, “Dynamic voltage restorer against balanced and unbalanced voltage sags: modeling and simulation,” presented at the IEEE Power Engineering Society General Meeting, Denver, CO, 2004.

[98] R. Omar, N. Rahim, M. Sulaiman. “Modeling and Simulation for Voltage Sags/Swells Mitigation Using Dynamic Voltage Restorer”, Journal of Theoretical and Applied Information Technology, 2009, pp 464 – 470.

[99] S. Shakil, K.K Srivastava, A.V Pandey, “Power Quality Enhancement and Sag Mitigation by Dynamic Voltage Restorer”, International Journal of Science and Engineering Research, Volume-4, Issue-6, June 2013, pp 999 – 1009.

[100] M. F. Firuzabad, M. Shahidehpour, R. Feuillet A. R. Ghahnavieh, "UPFC for enhancing power system reliability," IEEE Transactions on Power Delivery, vol. 25, no. 4, pp. 2881–2890, 2010.

[101] X. Wei, J. H. Chow, B. Fardanesh, and A.-A. Edris, “A common modeling framework of voltage-sourced converters for load flow, sensitivity, and dispatch analysis,” IEEE Trans. Power Syst., vol. 19, no. 2, pp. 934–941, May 2004

[102] H.A. Attia, H.W. Ping, Y. I. Al-Mashhadany, Design and analysis for high performance synchronized inverter with PWM power control, 2013 IEEE Conference on Clean Energy and Technology.

[103] S. Khanchi and V. Kumar Garg, "Unified Power Flow Controller (FACTS Device): A Review," International Journal of Engineering Research and Applications (IJERA), vol. 3, no. 4, pp. 1430-1435, Jul-Aug 2013.

[104] H.Samir, Z. S. Ahmed and D. Mohamed K. Y. I Djilani, "Modeling a Unified Power Flow Controller for the Study of Power System Steady state and Dynamic Characteristics," in 5th International Conference of Modeling, Simulation and Applied Optimization (ICMSAO), 2013.

[105] U. Abubakar, S. Mekhilef, K. S. Gaeid, H. Mokhlis, Y. I. Al Mashhadany, Induction motor fault detection based on multi-sensory control and wavelet analysis, IET Electric Power Applications journal, 2020, Vol. 14 Iss. 11, pp. 2051-2061 , doi: 10.1049/iet-epa.2020.0030

[106] Alok Kumar Mohanty, Amar Kumar Barik, “Power System Stability Improvement Using FACTS Devices” International Journal of Modern Engineering Research (IJMER), Vol.1, Issue.2, pp-666-672 ISSN: 2249- 6645.

[107] Y. I. Al-Mashhadany, “ANFIS-Inverse-Controlled PUMA 560 Workspace Robot with Spherical Wrist”, Elsevier Procedia Engineering journal, 2012, pp 700-709

[108] S.K Srivasta, “Advanced Power Electronics Based FACTS Controllers”, Asian Power Electronics Journal, Volume-4, No_3, December 2010, pp. 90 – 95

[109] Y. I. Al-Mashhadany, Inverse Kinematics Problem (IKP) of 6-DOF Manipulator By Locally Recurrent Neural Networks (LRNNs), International Conference on Management and Service Science August 24-26, 2010.

[110] A. Singh, A.Tiwari, “FACTS controllers for Reactive Power Compensation of Wind Energy Conversion System, S-JPSET, Volume-2, Issue-1, 2011, pp 41 - 48

[111] B. Singh, K.S Verma, P. Mishra, R. Maheshwari, U. Srivastava, A. Baranwal “ Introduction to FACTS Controllers: A Technological Literature Survey ”, International Journal of Automation and Power Engineering, Volume-1, Issue-9, December 2012, pp 193 – 234

[112] S.D Jebaseelan, R.R Prabu, “Reactive Power Control Using FACTS controllers”, Indian Streams Research Journal, Volume-3, Issue-2, March 2013, pp 1 – 15

[113] S. Rath, B.P Sahu, P. Dash, “Power System Operation and Control Using FACTS controllers”, International Journal of Engineering Research and Technology, Volume-1, Issue-5, July 2012, pp 1 – 5.

[114] Y. I. Al-Mashhadany, Modeling and Simulation of Adaptive Neuro-Fuzzy Controller for Chopper-Fed DC Motor Drive, 2011 IEEE Applied Power Electronics Colloquium, Malaysia, 18 – 19 April 2011, pp 110-115

[115] N. G. Hingorani, L. Gyugyi, Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems, IEEE, New York, 2000.
[116] N. N. Islam, M. A. Hannan, A. Mohamed and H. Shareef, " Improved Power System Stability Using Backtracking Search Algorithm for Coordination Design of PSS and TCSC Damping Controller", Plos One, 2016, 1-17.
[117] P. Simon and M. P. Selvan S. Sreejith Sishaj, "Investigations on Power Flow Solutions Using Interline Power Flow Controller (IPFC)," in Chennai and Dr.MGR University Second International Conference on Sustainable Energy and Intelligent System (SEISCON 2011), 2011.
[118] T. Lie and D.M. Vilathgamuwa J. ChenTjing, "Basic Control of Interline Power Flow Controller," IEEE Power Engineering Society Winter Meeting, vol. 2, pp. 521 - 525, 2002.
[119] L. Gyugyi and N. G. Hingorani, "Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems," in IEEE press New York, 2000.
[120] C. R. F. Esquivel, and H. A. Perez E. Acha, "Advanced SVC model for Newton-Raphson Load Flow and Newton Optimal Power Flow Studies," IEEE Transaction on power systems, vol. 15, no. 1, pp. 129–136, 2000.
[121] N. A. Aziz, N. A. A. Adnan, D. A. Wahab and A. H. Azman, " Component design optimisation based on artificial intelligence in support of additive manufacturing repair and restoration: Current status and future outlook for remanufacturing", Elsevier Journal of Cleaner Production Volume 296, 10 May 2021, 126401.
[122] A. A. Hussien, Y. I. Al Mashhadany, K. S. Gaeid, M. J. Marie, S. R. Mahdi and S. F. Hameed, "DTC Controller Variable Speed Drive of Induction Motor with Signal Processing Technique," 2019 12th International Conference on Developments in eSystems Engineering (DeSE), Kazan, Russia, 2019, pp. 681-686
[123] Y. H. Song and Y. Z. Sun Y. Xiao, "Power flow control approach to power systems with embedded FACTS devices," IEEE Trans on Power Systems, vol. 17, no. 4, November 2002.
[124] A. Ghosh, and A. Joshi G. N. Pillai, "Torsional Interaction Between an SSSC and a PSS in a Series Compensated Power System," IEE Proceedings on Generation Transmission and Distribution, vol. 149, no. 6, pp. 653–658, 2002.
[125] K. K. Sen, and C. D. Schauder L. Gyugyi, "The Interline Power Flow Controller Concept: a New Approach to Power Flow Management in Transmission Systems," IEEE Transactions on Power Delivery, vol. 14, no. 3, pp. 1115–1123, 1999.
[126] D. Qifeng and Z. Bomina T. S. Chung, "Optimal Active OPF with FACTS Devices by Innovative Load-Equivalent Approach," IEEE Power Engineering Review, vol. 20, no. 5, pp. 63–66, 2000.
[127] Y. I. Al Mashhadany, K. S. Gaeid and M. K. Awsaj, Intelligent Controller for 7-DOF Manipulator Based upon Virtual Reality Model, 2019 12th International Conference on Developments in eSystems Engineering (DeSE), Kazan, Russia, 2019, pp. 687-692.
[128] K. R. Padiyar, A. M. Kulkarni, Flexible AC transmission systems: A status review, Sadhana-Academy Proceedings In Engineering Sciences 1997; 22(6):781-796
[129] E. Acha, C. R. Fuerte-Esquivel, H. Ambriz-Pé rez, C. Angeles-Camacho, FACTS: Modelling and Simulation in Power Networks, Wiley, Chichester, 2004.

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