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REVIEW ON FLEXIBLE AC TRANSMISSION SYSTEM COMPONENTS IN THE DEREGULATED POWER SYSTEM

Ms. Seada Hussen
Department of Electrical and Computer Engineering
Addis Ababa Science and Technology University
Addis Ababa, Ethiopia

Ms. Frie Ayalew
Department of Electrical and Computer Engineering
Addis Ababa Science and Technology University
Addis Ababa, Ethiopia

Dr. Gopi Krishna Pasam
Department of Electrical and Computer Engineering
Addis Ababa Science and Technology University
Addis Ababa, Ethiopia

Abstract—**In deregulated power system, the flexible alternating current transmission system (FACTS) devices plays an important role for improving transmission system reliability, management, dynamic control of real and reactive power at significant buses and quality of power supply for sensitive industry. Many researchers have been developing innovative practices and procedures for effective implementation of FACTS components, but still plethora of nations are unable to use all FACTS devices such as static synchronous series compensator (SSSC), unified power flow controller (UPFC), static compensator (STATCOM, Static VAR Compensator (SVC), thyristor controlled Series Reactor (TCSR) and thyristor-controlled series capacitor(TCSC) due to their economical constrains and control issues in the online environment. This paper thoroughly reviews the impacts of different FACTS components on different issues of power system issues like stability, quality, control, load flow, power oscillation damping, avoidance of outage, reliability indices and so on. In particular this paper also includes the overview of FACT devices and its classification in different ways, different observations and identified the research gap to investigate further for effective utilization of FACTS devices in the modern power systems across the world.**

Keywords—***FACTS, SSSC, SVC , STATCOM, TCSC, UPFC etc.,***

I. INTRODUCTION

The FACTS controllers offer a great opportunity to regulate the transmission of alternating current (AC), increasing or diminishing the power flow in specific lines and responding almost instantaneously to the stability problems. Many researchers have been work with different FACT devices to improve stability on transmission line, for the last many years. L'Abbate .et al.(2010) [1] has been presented the technical, economic and environmental Features of FACTS and HVDC on transmission expansion plan.A.K.Mohanty.et al.(2004) [2] also presented Performance comparison of different FACTS controllers the likely future direction of FACTS technology. And FACTS applications to optimal power flow and deregulated electricity market.

M. M. Farsangi. etal.(2004) [3] was also presented the importance of identifying effective stabilizing signals for the FACTS devices in a power system. Naresh Acharya .et al.(2005) [4] was presents the benefit gained from fact devices, issue related to fact controller, cost associated to these device and practical. L.Yao. etal.(2005) [5] showed modified IEEE 30 bus system with/without the SSSC demonstrate the feasibility as well as the effectiveness of the SSSC for congestion management with high penetration of wind power in the netwok. O. L. Bekr. Etal.(2006) [6] was done on control model for a FACTS device (TCSC, SVC,UPFC) with concept of current injection method. Robson F . etal.(2009) [7] proposed FACTS to drain, or inject, energy from the line without changing its electrical characteristic. Adamczyk. etal.(2010) [8] was evaluated the performance of different FACT devices services and compares challenges of WPPs against FACTS solutions in the cause of wind generation.

Y. Han. etal.(2011) [9] discussed technology used for application of smart grid such as un-interruptible power supply (UPS), adaptive VAR compensator (AVC), static synchronous compensator (STATCOM), active power filter (APF), unified power quality conditioner (UPQC), micro-grid, solar and wind generation, and high voltage direct current (HVDC) transmission technology.A.. Ch.Rambabu. etal.(2011) [10] was done optimal locations of the multi-type FACTS devices to have a better voltage profile and power loss. P.Rames. etal.(2012)[11] eliminated the common dc link between the shunt and series converter transmits power through the transmission line at the third-harmonic frequency with lower cost of the DPFC than the UPFC. P. Gopi Krishna et al.(2012) [12] presented the usage of UPFC in the computations of available transfer capability (ATC) in the deregulated environment, optimal location of UPFC, its effect on ATC on IEEE- 9 bus test system.

M.Eslami et al.(2012) [13] was done on the necessary features of FACTS controllers and their potential to increase system stability and the location and feedback signals used for design of FACTS-based damping controllers were also discussed. A.K.M. Rezwanur Rahma.etal.(2013) [14] A genetic algorithm has been presented with larger parameters than previous methods to optimally locate FACTS devices in the power system by simulated IEEE 30 bus and IEEE 118 bus. A.R. Krishna.etal.(2013) [15] has been presented the right technology for improvement of power quality problem by using FACT device controller. Chonika .etal.(2014) [16] presented various types of FACTS devices such as: load tap changers, phase-angle regulators, static VAR compensators, thyristors controlled series compensators, interphase power controllers, static compensators, and unified power flow controllers and there classification based on steady sate and transient state stability and Power electronic and control technology. Bhagyashri G. etal.(2015) [17] increased the capacity of transmission line by super imposing dc in to ac transmission.

K. S. Mani.etal.(2016) [18] FACTS SSFC scheme based on a tri-loop dynamic error driven intercoupled input to VSC controller for power quality improvement, voltage stabilization, power losses reduction and power factor enhancement and is interfaced with Smart Grid-Distribution Network has been presented. Jena R. etal.(2016) [19] and Liao H.etal.(2017) [20] New FACTS topologies are emerging to ensure decoupled ac-dc interface, improved voltage security, reactive compensation, voltage and power factor improvement, and loss reduction. Akanksha Singh.et al.(2017) [21] was done on comparison on with and without STATCOM and TSC to control the power flow by testing five bus system using MATLAB.

The essential features of FACTS controllers and their potential to improve system stability is the prime concern for effective & economic operation of the power system. The motivation behind this review is an increasing steady state power system control problems and the need of controlling the active and reactive power flows in a transmission line by controlling its series and shunt parameters. This increases the requirement of comparison of different FACTS controllers in the power system for stability enhancement and selecting appropriate method for the problem after getting the gap on reviewed paper. The general objective of a review is to summarize and review different fact controller used in transmission system and finding the gap on the area.

II. OVERVIEW OF FACTS DEVICES

Most of FACTS devices were developed using power electronic components to improve the performance of weak AC Systems and to make long distance AC transmission feasible. Moreover, FACTS can help to solve various technical problems in the interconnected power systems. Different types of fact devices described in shown below. The FACTS devices are used in the different circuits by the symbols as shown in Fig.1.

A. Static compensator (STATCOM)

The STATCOM is a solid-state synchronous condenser connected in shunt with the AC system. Nodal voltage magnitude or the reactive power injected at the bus controlled by adjusting the output current [16].

B. Static synchronous series compensator (SSSC)

The SSSC is a series device of flexible AC transmission systems family using power electronic to control power flow and improve transient stability on power grids.in place of using capacitor and reactor banks [22-24].

C. Unified power flow controller (UPFC)

The UPFC consists of a static synchronous series compensator (SSSC) and a STATCOM, connected in such a way that they share a common DC capacitor. The UPFC, by means of an angularly unconstrained, series voltage injection, is able to control, concurrently or selectively, the transmission line impedance, the nodal voltage magnitude, and the active and reactive power flow through it. It may also provide independently controllable shunt reactive compensation [16][25][26][35-48].

D. Static VAR Compensator (SVC)

An electrical device used for providing fast-acting reactive power compensation on high voltage electricity transmission networks and SVCs are part of the FACTS device family, regulating voltage and stabilizing the system. It is known that the SVCs with an auxiliary injection of a suitable signal can considerably improve the dynamic stability performance of a power system [28-34].

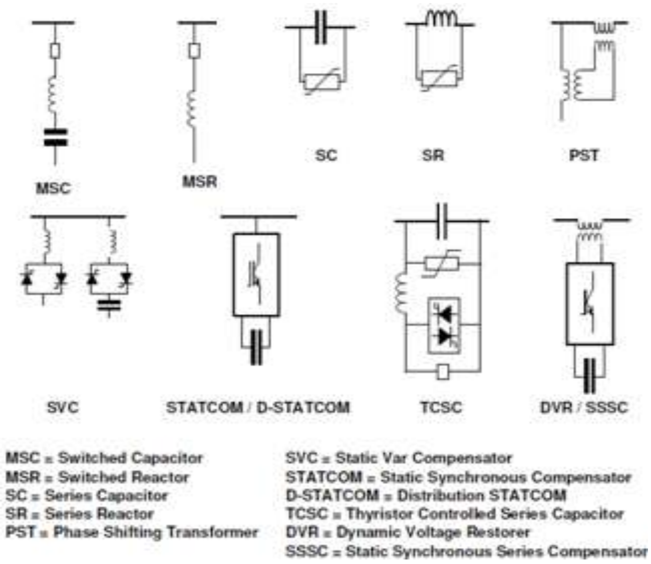

Fig. 1: General symbol of some FACT devices

E. Thyristor controlled Series Reactor (TCSR)

A TCSR consists of a series reactor in parallel with TCR so as to provide smooth variable series reactance control [58].

F. Thyristor-controlled series capacitor(TCSC)

Oscillations constitute a hazard to power system stability .The task of TCSC is to damp low frequency inter-area power oscillations between the power systems on either side of the inter-connection [60-66].

III. CLASSIFICATION OF FACTS

After FACTS devices can be classified according to the power electronics technology used for the converters and as a voltage source controllers.

A. **Thyristor-based controllers[95]**

This category includes the FACTS devices based on thyristors, namely the SVC, the TCSC, the TCPST and the DFC;

B. **Voltage source-based controllers**

These devices are based on more advanced technology like Gate Turn-Off (GTO) Tyristors, Insulated Gate Commutated Thyristors (IGCT) and Insulated Gate Bipolar Transistors (IGBT). This group includes the STATCOM, the SSSC, the IPFC and the UPFC.

C. **Traditional Classification**

FACTS devices can be also traditionally classified according to their connection, as shown in Fig. 2.

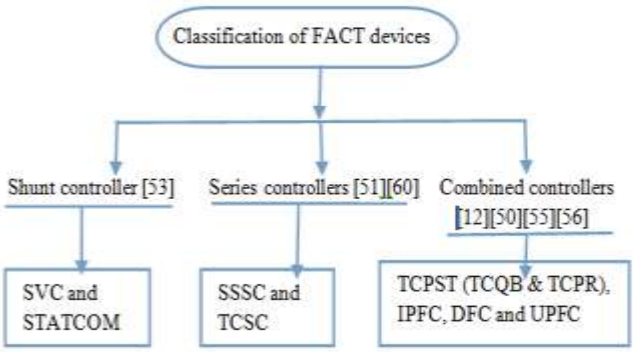

Fig. 2: Traditional classification of FACTS

D. **Modern Classification**

In the modern technology FACTs are classified in to two generations for realization of power electronics-based FACTS controllers: the first generation employs conventional Thyristor-switched capacitors and reactors, quadrature tap-changing transformers, that second generation employs gate turn-off (GTO) Thyristor-switched converters as voltage source converters (VSCs). The first generation has resulted in the Static Var Compensators (SVC), the Thyristor- Controlled Series Capacitor (TCSC), and the Thyristor-Controlled Phase Shifter (TCPS). The second generation has produced the Static Synchronous Compensators (STATCOM), the Static Synchronous Series Compensators (SSSC), Static switch filter compensator (SSFC), the Unified Power Flow Controller (UPFC) [73][74][75] and the Interline Power Flow Controller (IPFC).the system, large dynamic swings between different parts of the system and bottlenecks [76].

There is also new generation in addition to first and second generations which is called as a last generation or DFACT devices. They are smaller and less expensive than traditional FACTS. DFACT devices are used in distribution systems, while FACT devices are used in transmission systems. The most examples of DFACT devices are D-STATCOM and DSSC. In this paper, the another classification of FACTS devices based on principle and impacts on system performance is described in the section-E.

E. **Classification based on principle**

Flexible AC transmission system devices are classified in three different categories depend on its principle as shown Fig. 3 [82 - 87].

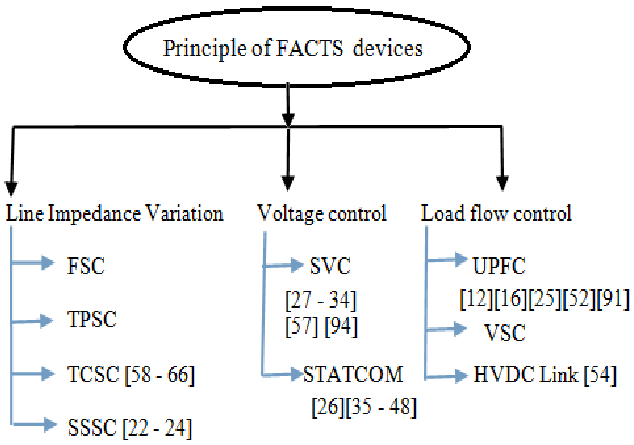

Fig. 3: Classification based on principle

The FACT devices has several impacts on the transmission system performance described in Table 1.

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Table 1: Impacts of FACTS on system performance

Impacts on system performance	FSC	TPSC	TCSC	SVC	STATCOM	UPFC	VSC
Load Flow	Small	Small	Medium	___	___	Medium	Strong
Stability	Strong	Strong	Strong	Medium	Medium	Strong	Strong
Voltage Quality	Small	Small	Small	Strong	Strong	Strong	Strong
Voltage control	Medium	___	Strong	Strong	Strong	Strong	___
Reactive Power Control	Strong	___	___	Strong	Strong	Strong	Strong
Avoidance of outage	___	___	Strong	Strong	Medium	Strong	___
Unbalance Control (Option)	___	___	Medium	Strong	___	Strong	Strong
Power Oscillation Damping (POD)	___	___	___	Strong	___	___	Strong
Thermal Limit Action	Medium	Medium	Strong	Strong	Strong	Strong	___

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F. Comparison of different Research works

The researchers work on FACTS as per this paper references is shown in Fig. 4 by rising order using pyramid and the cost of different FACTS devices are shown in Fig. 5.

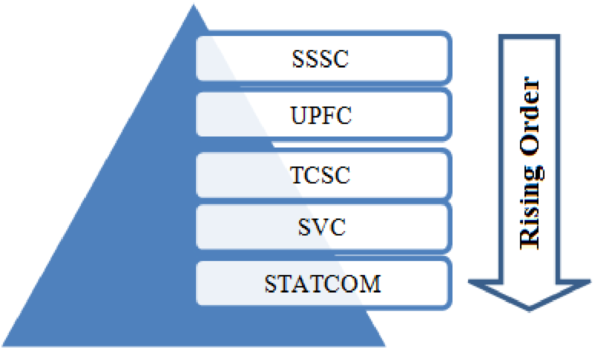

Fig. 4: Amount different works done by researchers

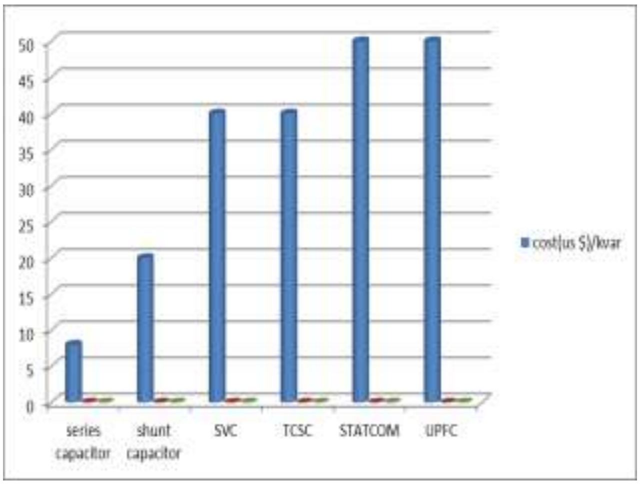

Fig. 5: Costs of different FACT devices

G. Benefits and challenges of FACTS [77]

- FACTS devices stabilize transmission systems with increased transfer capability and reduced risk of line trips.
- The improved stability in a power system substantially reduces the risk for forced outages, thus reducing risks of lost revenue and penalties from power contracts.
- FACTS devices can help to provide the required quality including constant voltage and frequency, and no supply interruptions. Voltage dips, frequency variations or the loss of supply .
- FACTS installation has the flexibility for future upgrades and requires small land area.
- The construction of new transmission line has negative impact on the environment.
- Utilizing the transmission systems optimally with the use of FACTS, the total number of line fault is minimized, thus reducing the maintenance costs.
- FACTS devices comes from the additional sales due to increased transmission capability, additional wheeling charges due to increase transmission capability and due to delay in investment of high voltage transmission lines or even new power generation facilities.
- As compared to conventional devices, FACTS controllers are very expensive.
- It makes system complexity than the conventional method.

IV. Observations and Key References of the Review

This section includes the overall observations and the key references of different research works on FACTS devices.

- The UPFC is the most powerful and versatile FACTS device. The line impedance, terminal voltages, and the voltage angle can be controlled by it as well [6].
- All thyristors based technology is has slower response times than modern fully controllable semiconductor devices [9].
- The multi-type FACTS devices located at their own optimal locations is observed to have a better voltage profile and power loss [10].
- Typical delivery time and size of CSC is higher than other device.[16]
- VSC-based FACTS devices including IPFC and SSSC, shunt devices like STATCOM, and combined devices like UPFC, are more complex and usually modeled as controllable sources. [78, 79].
- A new hybrid model for OPF incorporating FACTS devices was investigated to overcome the classical optimal power flow algorithm where load demands, generation outputs, and cost of generation are treated as fuzzy variables. An improved GA was presented to solve OPF problems in power system with FACTS where TCPS and TCSC are used to control power flow [80, 81].
- It is observed that the damping introduced by the SVC and STATCOM controllers with only voltage control was lower than that provided by the PSSs and the STATCOM provides better damping than the SVC as this controller is able to transiently exchange active power with the system [82].
- Some researchers concerned with enhancing the steady state and dynamic performance of the Flexible AC Transmission System (FACTS) using Computational Intelligence methods, like Genetic Algorithms (GA), Fuzzy Logic (FL), Neural Networks, (NN), and Adaptive Neuro-Fuzzy Inference Systems (ANFIs).

V. Conclusions and Recommendations

A. Conclusions

Most researchers are doing with STATCOM and UPFC but still there is a gap in this area especially in the developing countries. UPFC works best for control of power flow, DVR as a series compensator is used for voltage sag compensation and STATCOM as a shunt compensator is employed for compensation of both reactive power and voltage sag. As STATCOM, DVR, UPS etc., are useful for compensating a specific kind of power quality problems, it has become significant to develop a new type of Unified Series-Shunt Compensator (USSC) which can reduce a wider range of power quality problems. FACTS based Static Switched Filter Compensator (SSFC) scheme for effective power quality enhancement, voltage stabilization, power factor improvement and losses reduction in distribution grid networks with the distributed wind energy interface. Generally this paper shows which FACT devices are used to improve power quality, voltage profile, stability (either dynamic or static) and soon, with high controlling capability.

B. Recommendations

The recommendation only based on the references including in this paper.

- ❖ VSC based devices like STATCOM, SSSC, or UPFC are more attractive, because their operation in not so strongly dependent on the grid conditions for stability of wind generation.
- ❖ Combining STATCOM with TSC to extend operational range in addition to more sophisticated control systems will improve the operation facts devices
- ❖ Improvement in semiconductor technology with higher current carrying capability and higher locking voltages could reduce the cost of facts devices and extend their operation range.
- ❖ It is recommended that Future applications of FACTS devices include renewable energy resources, residential and commercial smart building, residential use of hybrid DC-AC grid, increased use of vehicles-to-grid and vehicles-to house, battery charging system, and street, buildings and airports light emitting diode (LED) lighting technology.
- ❖ For better reduction of ripple and total harmonic distortion at the AC side recommended that working with multi-stage voltage source inverters with switching strategies based on double carrier, inverse sine carrier and optimized switching techniques.

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