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FACTS Devices as a Solution to Power Industries Problems: A Review

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Abstract:

With an ever-increasing demand for power and establishment of new industries with high load demand, the need to for constant upgrade of powers system network is high. Such transmission networks are prone to external disturbances from loads, environment and other sources which leads to low power quality. Sudden application or removal of large loads. Large loads are known to draw more reactive power than the generated reactive power which lead to reactive power imbalance which can lead to total system collapse. In this paper, a critical review of how Flexible Alternating Current Transmission Systems (FACTS) devices are used to mitigate such issues to ensure power quality is done. Previous work on the integration of different FACTS devices were review to establish the advantage of FACTS devices over conventional solutions to power transmission problems.

Keywords: *FACTS devices, Power Industries.*

Introduction

The current desire for clean energy and the developments of Renewable energy resources, power systems are facing instability issues when the conventional energy sources are hybridized with power electronics converter-based sources. In order to mitigate the stability issues, the introduction of technologies like FACTS devices have proved effective as a solution to stability issues.

FACTS are static power electronic devices that are installed and used in AC transmission networks to enhance the capability of transferring the power for providing the controllability and stability (Khan, et al., 2021). They are categorized into Series controllers, Shunt controllers, Series-Shunt controllers and Series-Series controllers.

Shunt Compensation

The idea of series compensation is to supply reactive power to a transmission line to increase the transmittable power to make it more compatible to load demands (Rashid, 2023) In the shunt compensation, a current is injected into the system at the point of connection. This can be implemented by varying a shunt impedance, a voltage source, or a current source (Rashid, 2023). Shunt compensators include Thyristor-controlled Reactor (TCR), Thyristor Switched Capacitor (TSC), Static VAR Compensator (SVC), Advanced Static VAR Compensator also known as static compensator (STATCOM).

Series Compensation

The idea of series compensation is to introduce voltage in series to the transmission line to control current flow and thereby the power transmission from sending end to receiving end (Rashid, 2023). In principle, variable frequency multiplied by the current flowing through the line represents voltage injected to the line. The series compensator supplies or consumes variable reactive power as long as the voltage is in phase quadrature with the line current (Rashid, 2023). Series compensators include Thyristor-Switched Series Capacitor (TSSC), Thyristor-Controlled Series Capacitor (TCSC), Thyristor controlled series reactor (TCSR), Static synchronous series compensator (SSSC).

Combined Series-Shunt Compensators

These controllers combine the action of series and shunt controllers by injecting voltage in series to the line and current in parallel to the line at the point of connection. This combined series and shunt controllers are operated in a coordinated manner through a DC-link. This type of controller is the Unified Power Flow Controller (UPFC).

Combined Series-Series Compensators

These controllers are a combination of two of more series compensators connected in series to the transmission line which are operated in a coordinated manner. They provide reactive power compensation to the line independently. This type of compensator is the interline power flow controller (IPFC).

FACTS devices can also be classified into two generations based on technological features, which are the first and second generation. The first generation used thyristors with ignition controlled by gate (SCR) and the second generation used semiconductors with ignition and extinction-controlled gate (IGBTS, IGCTS, GTO's, MCTS, etc.).

The main difference between second and the first-generation devices is the ability to generate reactive power and ability to interchange active power. The first-generation FACTS devices operate like passive elements by using impedance or tap changer transformers controlled by thyristors. The second-generation FACTS devices operate like angle and module-controlled voltage sources and without inertia, based in converters, employing electronic tension sources (voltage source control, three phase inverters, synchronous voltage sources, auto-switched voltage sources,) fast proportioned & controllable and static synchronous voltage & current sources (Pathak, 2020).

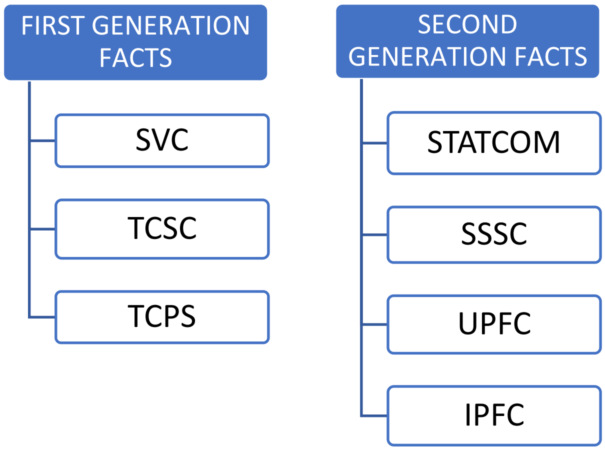

Figure 1. Generation of FACTS devices

Reviewed Work

In Khan, et al. (2021) the optimal reactive power dispatch (ORPD) embedded with two effective controllers including the Static VAR Compensator (SVC) and Thyristor Control Series Capacitor (TCSC) is solved using a Modified Lightning Attachment Procedure Optimizer (MLAPO). The impact of incorporating SVC and TCSC, and performance of the algorithm have been verified through the IEEE 30-bus and IEEE 57-bus systems. Compared to those without the FACTS devices, the simulation reveals that the optimal allocation of the controllers reduced the power loss and operating cost, improve the voltage profile considerably.

In Pathak (2020), the voltage profile improvement and power loss reduction of the Nigeria 330 kV transmission network using the unified power flow controller (UPFC) as an optimal FACTS device is presented. The study utilized the power systems analysis toolbox

(PSAT) 2.1.10 that is embedded in MATLAB 2017a to model the Nigeria 330 kV transmission network. The Newton Raphson load flow algorithm was used to carry out the load flow study using data obtained from the transmission company of Nigeria. Voltages less than 0.95pu (313.5kV) were assumed to be low voltage while those greater than 1.05pu (346.5kV) were assumed to be high voltage. A base case load flow study was carried out without the use of UPFC to determine weak buses. The outcome of the base case simulation without the use of the UPFC showed that seven buses were operating outside the lower operating limit. After compensation using the UPFC, the operating voltages at each of the buses were found to be within the stated limit. The transmission line losses were found to have been reduced from 71.66MW to 32.95MW and from 76.7MVAR to 41.89MVAR respectively. The UPFC was used to regulate the voltage magnitude and phase angle. The load flow study before compensation identified buses with low voltages as thus: Abuja (0.915214pu), Gombe (0.885320pu), Jos (0.892145), Kaduna (0.925412pu), Kano (0.814312pu), Maiduguri (0.800211pu) and Makurdi (0.892312pu). The simulation of the network with UPFC substantially improved the voltages at Abuja (0.97120pu), Gombe (0.96439pu), Jos (0.96763pu), Kaduna (0.95604pu), Kano (0.95843pu), Maiduguri (0.95604pu) and Makurdi (0.97349pu). The result of the power flow analysis after compensation with UPFC showed a significant reduction in the total system voltage violations with all the bus voltages within the specified limit of 0.95 – 1.05pu.

In Onah (2023) the effects of STATCOM on the performance of the Nigeria 330 kV, 34-bus power system network was investigated. The power flow equations describing the steady-state conditions of the system network before and after compensation were modeled and simulated in the NEPLAN software environment. The results from the analysis revealed that before the application of STATCOM. Seven buses were found to have their bus voltages below acceptable values, which include Kano 305.097 kV, New Haven 313.249 kV, Kaduna 309.721 kV, Jos 305.563 kV, Makurdi 304.787 kV, Gombe 304.443 kV and Yola 300.375 kV. However, the introduction of STATCOM into the modeled power system revealed a compensated voltage at the affected buses of Kano 330 kV, New Haven 330 kV, Jos 326 kV, Kaduna 330 kV, Gombe 330 kV, Makurdi 330 kV and Yola 330 kV. Also, the total system losses were reduced from 49.335 MW to 44.719 MW and 410.226 MVar to 399.561 MVar which represents real and reactive power loss reduction by 9.4% and 2.4% respectively. Thus, this study has evidently established that the deployment of STATCOM has the capacity to positively impact the Nigeria power system network by improving the voltage profile and reducing the total power loss thereby enhancing the electric power transmission system.

In Justin, et al. (2021) a study of voltage collapse in Nigeria Power Network is presented. The study involves series of events accompanying voltage instability which lead to a blackout or abnormally low voltages in a significant part of the power system. The data collected comprised the series of system collapse experienced by the Nigeria power system since 2000 to 2020 which were analyzed so as to view the frequency of the occurrence of the collapse. To reduce the incidence of system collapse on the power system FACTS devices was suggested. The compensators presented in this work are SVC, STATCOM, TCSC, SSSC and UPFC. PSAT software which makes use of Newton-Raphson's iterative method was used to simulate the existing 52-bus system of Nigeria which displayed high accuracy and converged in few numbers of iterations. SVC and STATCOM were first used separately to compensate bus1 (0.9673pu) while TCSC, SSSC and UPFC were later used separately to compensate the system. Results obtained showed that the use of dynamic shunt compensators (SVC and STATCOM) maintained the bus 1 voltage at 0.9673pu while the use of series compensators (TCSC, SSSC and UPFC) slightly maintained a power flow of 80MW and bus 1 voltage at 0.9673pu after several increases in loadings. It is with this that the research work presents the use of series compensators on the transmission lines as the optimal approach to voltage collapse in Nigerian Power system. 11 buses out of the existing 28-bus system of Nigerian transmission system was used to study the power flow on the lines using series compensators, shunt compensators, and load shedding. Hence the series compensator remains the optimized approach to voltage collapse margin reduction which is expected to be optimally placed along transmission line from bus 8 to bus 9 since it has the lowest loss sensitivity index.

In Benslimane & Benachiba (2015) the performance of IPFC in multiline transmission system was investigated. The IPFC system proposed in this research work consists of two back-to-back VSC connected in series with the transmission lines. Inverter and converter circuits were designed by using IGBTs. IPFC effectively maintains voltages of transmission lines by compensating reactive power in case when line gets heavily loaded. Simulation model and hardware of proposed system have demonstrated the usefulness of IPFC on transmission line models. MATLAB Simulink is used for simulating the transmission line models and analyzing the results with IPFC and without IPFC. The IPFC is used to enhance the power quality of system network. Investigating voltage compensation via IPFC shows the increase in active power and reactive power of the system network. Results from simulation and hardware model shows effectiveness of IPFC.

In Woldesemayat & Tantu (2022) the static security assessment (SSA) of the Ethiopian Electric Power (EEP) 400kV system through integration of IPFC under N-1 contingency condition is investigated. The Bus and line loading-based composite severity indices (CSI) were utilized to determine the state of the system and to get an optimal location for interline power flow controller (IPFC) placement. The optimal sizing of IPFC was done by using Grey Wolf Optimization (GWO) algorithm. From the analysis it was found that the Gelan to Sebeta and Gelan to Holeta branches are found to be with higher voltage instability than the others and identified as the primary bus for IPFC placement. Integrating the 50MVA-rated IPFCs within the system reduced the severity margin of bus voltage violations and line overloading. The possibility of bus voltage magnitude violation and the line-overloading situation is effectively reduced when simulating the system with IPFC. The average bus voltage severity index (BVSI) without and with IPFC cases was found as 217.243% and 2.641% respectively. The average line severity index (LSI) without and with IPFC cases were found as 39.448% and 15.283% respectively. Moreover, the total line loss under severe N-1 contingency scenarios without and with IPFC integration was 437.783 MW and 63.136 MW respectively. From analysis, it was observed and concluded that the static security of the EEP 400 kV system under N-1 contingency conditions is effectively improved by the integration of IPFC.

In Chiatula, et al. (2020), the results of the study that assess the application of FACTS technologies into the expansion plans of the Transmission Company of Nigeria; as it transfers power through transmission lines to load centers is shown. The following studies were carried out; load-flow analysis, voltage stability studies and economic analysis on the different cases. The cases compare using two options; New transmission assets and UPFC installation for the Lagos region South-West Nigeria. From the cases studied, the latter alternative which is the application of UPFC was seen to be most beneficial in the following ways; least cost, mitigation of right of way issues, failure down time is reduced, improvement of voltage profile on the busbar studied & de-loading of heavily loaded lines by diversion to under-utilized transmission lines. These results ultimately present the plausibility of using FACTS devices, the UPFC specifically in the Transmission Network of Nigeria.

In Daealhaq, Hammadi & Hassan (2021), three basic types of FACTS devices which are: Thyristor Controlled Series Capacitor (TCSC), Static Var Compensator (SVC), and Unified Power Flow Controller (UPFC), were studied in order to assess the performance improvement by optimal allocation using Differential Evolution (DE) on the IEEE 30-bus test system. The objective of the research was to reduce power losses and improve the voltage profile in an IEEE 30-bus test system. The system performance was assessed with and without each FACTS device under different scenarios of load increase at up to 150% of the base case. The addition of UPFC devices in the optimum location (line 4) reduced the active and the reactive losses of the system to 15.755, 16.198, and 16.743 MW and 61.227, 62.516, and 62.854 MVar, respectively, while the installation of TCSC devices in transmission line 44 reduced the losses to 15.531, 15.764, and 15.934 MW for active power and 63.560, 63.865, and 64.706 MVar for reactive power. Bus 21 was found to be the best place to install an SVC device, with total active and reactive power losses of 14.897, 15.674, and 15.864 MW and 62.015, 63.278, and 64.214 MVar, respectively, with varying loads. The results obtained are encouraging in terms of reassessing electrical restructuring.

In Kumar & Kumar (2020) FACTS devices TCSC and SSSC, are incorporated in IEEE-14 bus test system for the analysis of their performance in a relation of reactive power and voltage magnitude. The IEEE 14 bus test system is designed on MATLAB/SIMULINK environment. The steady-state modelling of these devices has been carried out by deriving the static equations. The WLS technique is used for measuring system parameters on individual buses. The techniques help in reducing error and improving accuracy in measuring of system parameters. The weak buses on which the voltage profile is poor have been identified. The FACTS devices proposed are located on these buses. The voltage profile on these buses improves remarkably. The size of the FACTS devices and their allocation has been determined on the basis of voltage magnitude and reactive power required on those buses during loading conditions. The TCSC and SSSC are located at different location identified on the basis of weak voltages on the buses of IEEE 14 bus test system. The FACTS devices are located independently in IEEE test system at different location to obtain the unity or specific value of bus voltage. It is identified that while the placement of FACTS devices at a different location will help in improving the system performance. The allocation of TCSC at a different location on the IEEE Bus System will lead to improvement in voltage profile from 1.5 to 4.9% with respect to without FACTS devices. The reactive power constraint of the power system in IEEE System is varied from 13.0 to 48.2% as per the different location identified on the basis of operation of the Basic IEEE 14 bus test system. Similarly, the SSSC implementation on IEEE bus test system is arranged on the basis of voltage profile and Reactive Power profile of Buses as per the values identified by the normal operation of the power system under loading conditions. The variation in system parameters is identified during placing of SSSC to maintain the bus parameters as per the specified limit. The voltage profile of the power system varies on implementation of SSSC from 1.2 to 4.4% with respect to without FACTS device. The Reactive Power flow between buses will be varied by SSSC implementation at a different location from 4.9 to 74.2% with respect to the case without FACTS device. Finally, it is concluded that the SSSC implementation in IEEE is more effective FACTS device as compared to TCSC in respect of Reactive Power compensation. The SSSC help in the improvement of the Voltage profile of the system but not as much TCSC does. On the basis of results obtained on IEEE 14 bus test system with FACTS devices will help in improvement of voltage profile and reactive power compensation of the test system during the loaded condition.

Benefits of FACTS to Power Industry Problems

Utilizing FACTS devices for addressing stability issues faced by power systems like issues associated with reactive power imbalance, power losses by controlling transmission line parameters including phase angle, voltage, active and reactive power becomes beneficial. Although FACTS devices are more expensive than conventional solutions to transmission problems, their effectiveness means they can't be ignored.

Conclusion

This paper is aimed towards the benefits of utilizing FACTS devices with the purpose of improving the operation of an electrical power system. Performance comparison of different FACTS controllers by relevant work was reviewed. The reviewed work help establish the effectiveness of FACTS devices as a solution to transmission issues faced by the power industries. Furthermore, the effectiveness of FACTS devices is enhanced by optimal placement. In addition, installation of FACTS devices to transmission systems in the real-world are known to be more expensive than the conventional solutions to transmission issues. However, it can prove to be cost effective as cost effectiveness is an economic decision by planners in the power industry.

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