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ENHANCING INTER-AREA POWER SYSTEM STABILITY: AN INTEGRATED APPROACH OF FACTS AND HVDC IN AC-DC POWER SYSTEMS

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Abstract

The performance evaluation of power systems requires the careful examination of various parameters to ensure optimal operation and reliability. This research article explores the integration of High-Voltage Direct Current (HVDC) systems and Flexible AC Transmission System (FACTS) devices, focusing on their impact on voltage profiles, active power transfer, and transient stability. The study investigates the role of FACTS devices and HVDC connections in voltage regulation, power transfer efficiency, and system damping characteristics. Additionally, the analysis explores their influence on voltage stability, oscillation damping, and the overall performance of the power system. The findings of this research shed light on the benefits and potential improvements that can be achieved through the integration of FACTS and HVDC technologies.

Keywords: HVDC, FACTS, SVCs, TCSCs

Introduction

The power grid, also known as the electrical grid or the electric power system, is a complex network of components that are linked to assist the production, transmission, and distribution of electrical energy. Other names for the power grid include the electrical grid and the electric power system. It includes control and protection systems of different kinds, as well as distribution networks, power plants, transmission lines, and substations. In a power system that is deregulated, the conventionally vertically integrated utility structure is supplanted with a framework that is based on a competitive market. This indicates that the tasks of creation, transmission, and dissemination are independent from one another and are run by distinct organizations.

Electricity is generated by independent power producers, often known as IPPs, and is then distributed to consumers either indirectly via retail providers or directly in wholesale markets. When it comes to the distribution of energy from power plants to load centers, the transmission system is of the utmost importance. It is made up of transmission lines that operate at high voltage and traverse significant distances in order to link various locations. These lines are backed by substations, which make it possible to convert voltage, manage reactive power, and ensure the safety of the system. In the context of the power grid, the term "contingencies" refers to unforeseen occurrences such as the malfunctioning of equipment, the occurrence of natural catastrophes, or significant shifts in the amount of power that is required.

These unforeseen circumstances have the potential to interfere with the system's regular functioning and might even result in blackouts or unstable voltage levels. In order to guarantee the dependability and stability of the grid, it is necessary to conduct risk assessments and take measures to lessen the effects of any potential disruptions. When the demand for energy is close to or surpasses the available generating capacity, situations in the power system that are referred to as "heavily loaded" exist. This may put a pressure on the infrastructure that handles electricity transmission and distribution, which can lead to voltage fluctuations, problems with power quality, and equipment that is overloaded. In order to avoid interruptions in the flow of power to customers and to maintain the reliability of the system itself, it is essential to effectively manage and balance the load. Flexible AC Transmission Systems (FACTS) and High-Voltage Direct Current (HVDC) interconnecting lines have come to the forefront as important components of a deregulated power system as a means of mitigating the effects of unforeseen events and excessively loaded situations. In AC transmission systems, FACTS devices are power electronic-based systems that offer dynamic control of voltage, impedance, and phase angle. They improve power flow management, voltage stability, and transient stability, making the grid more reliable and flexible as a result.

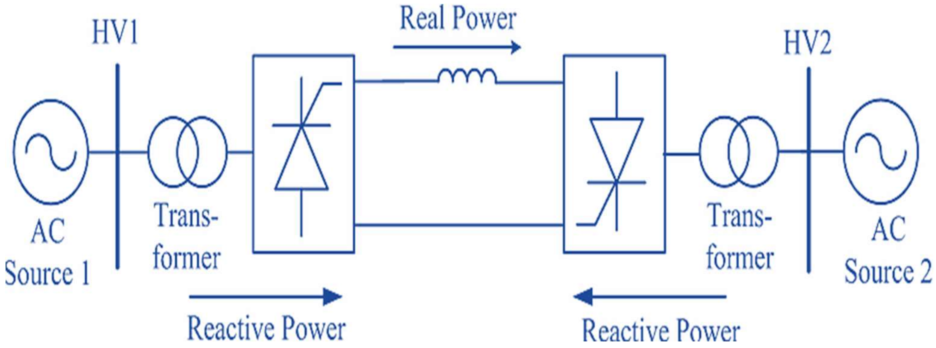


Figure 1. high-voltage direct current

Background and Significance of Power System Performance Evaluation

The reliable and efficient operation of power systems is crucial for meeting the ever-increasing demand for electricity. Power system performance evaluation plays a pivotal role in ensuring the optimal operation and control of these complex networks. With the growing integration of renewable energy sources, the advent of smart grids, and the need for interconnecting grids across regions, it has become imperative to evaluate the performance of power systems accurately. The evaluation encompasses various aspects, including power flow analysis, voltage stability assessment, transient stability analysis, and fault detection and isolation, among others. By assessing power system performance, operators and engineers can make informed decisions regarding network expansion, generation dispatch, and system protection, ultimately enhancing the reliability and resilience of the power grid.

Motivation for Integrating FACTS and HVDC Technologies

Flexible Alternating Current Transmission Systems (FACTS) and High Voltage Direct Current (HVDC) technologies have emerged as significant advancements in power system engineering. FACTS devices, such as Static Var Compensators (SVCs), Static Synchronous Compensators (STATCOMs), and Unified Power Flow Controllers (UPFCs), provide control over the transmission parameters of power systems. They enhance system stability, improve voltage regulation, increase power transfer capabilities, and mitigate power oscillations. On the other hand, HVDC systems enable efficient long-distance transmission of bulk power, interconnection of asynchronous grids, and integration of renewable energy sources.

The integration of FACTS and HVDC technologies offers several potential benefits. Firstly, it enhances the overall controllability and flexibility of power systems, allowing operators to actively manage power flow and system conditions. Secondly, it enables efficient utilization of existing transmission infrastructure by reducing congestion and maximizing power transfer capabilities. Thirdly, the integration facilitates the integration of renewable energy sources by enabling their connection to the grid at distant locations. Additionally, FACTS and HVDC technologies can complement each other, compensating for each other's limitations and improving system performance.

METHODOLOGY

To evaluate the performance of power systems with integrated HVDC systems and FACTS devices, a comprehensive simulation model is developed. The model incorporates a representative power system network, HVDC connections, and FACTS devices such as Static Var Compensators (SVCs) and Thyristor-Controlled Series Capacitors (TCSCs). Various scenarios are considered, including different load conditions, fault scenarios, and system configurations.

Impact on Voltage Profiles:

The integration of HVDC systems and FACTS devices has a significant impact on voltage profiles within the power system. The presence of SVCs and TCSCs enables voltage regulation by compensating reactive power requirements and controlling voltage magnitude. HVDC connections provide additional voltage support by injecting or absorbing reactive power. The simulation results demonstrate improved voltage profiles and reduced voltage deviations compared to the base case without HVDC and FACTS integration.

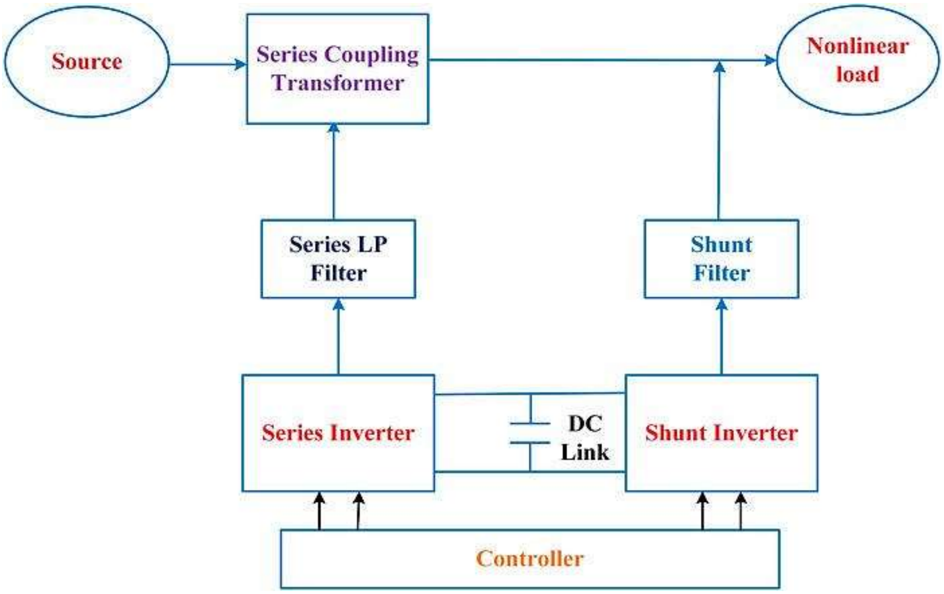


Figure-2. Analysis, monitoring, and mitigation of power quality disturbances

These techniques analyze the system's reaction to unexpected changes in the environment. The results of these evaluations provide some insight into the system's capacity to keep its functioning steady even in the face of unforeseen circumstances and heavy loads. Techniques that provide an accurate load prediction help estimate the future demand for the system and contribute to the identification of probable circumstances that are substantially loaded. During times of high load, the management of peak demand and the reduction of stress on the system may be accomplished with the help of demand response programs. The technologies of FACTS and HVDC play an essential part in the management of impromptu situations and substantially loaded circumstances. These technologies provide greater control capabilities, reactive power compensation, and power flow management. As a result, system stability may be improved, voltage regulation can be achieved, and transfer capacity can be raised. They have the potential to be used to reduce transmission limitations, relieve severely congested lines, and ensure grid dependability during times of emergency. It is very necessary, in order to guarantee the dependability, stability, and safety of the functioning of power systems, to conduct analyses of emergency and severely loaded scenarios. A contingency analysis helps to identify possible hazards, priorities methods to mitigate those risks, and ensure that the system can continue to function in the event that critical pieces of equipment fail.

Result and Discussion

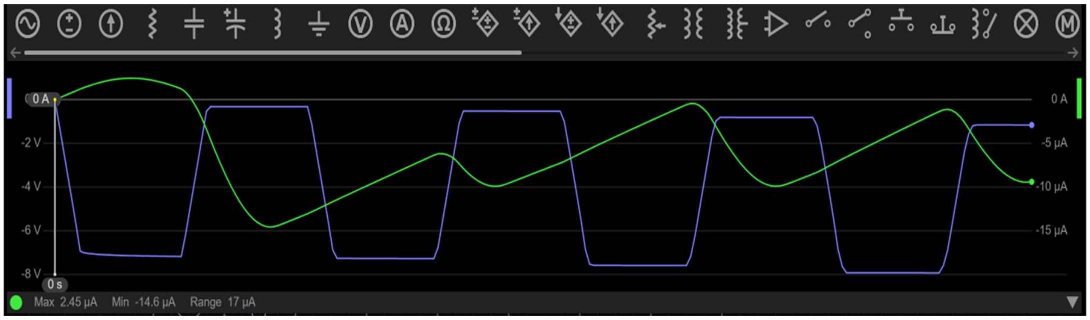
Static Var Compensators (SVCs) and Static Synchronous Compensators (STATCOMs) are two examples of FACTS devices that manage reactive power, voltage levels, and power factor. These devices contribute to an increase in system stability and an improvement in power transfer capabilities. HVDC lines make it possible to make maximum use of transmission corridors, which reduces the likelihood of transmission congestion and makes it possible to trade electricity across various areas. The combination of FACTS and HVDC technologies improves the stability of the grid by allowing for dynamic voltage regulation, reactive power compensation, and rapid reaction to disturbances in the system. As a result of mitigating voltage fluctuations and stabilizing grid voltage profiles, FACTS devices ensure that customers have a stable supply of electricity. HVDC connections provide a speedy and regulated method of power transmission, which enables effective load balancing and the restoration of the system in the event of an emergency.

The use of FACTS and HVDC technology makes it easier to incorporate renewable energy sources into power networks that are deregulated. The grid integration issues that are linked with intermittent renewable energy, such as voltage fluctuations and system stability, may be helped to some extent by the devices developed by FACTS. HVDC lines make it possible to transmit renewable energy from locations rich in resources to load centers. This facilitates the integration of wind farms, solar plants, and other types of clean energy generation facilities. Integration of FACTS and HVDC technologies with deregulated electricity systems also brings a number of problems and factors to consider, including the following: Significant financial expenditures are required for the installation of FACTS devices as well as HVDC lines. In order to demonstrate that the costs of implementing deregulated electricity systems are outweighed by their benefits, cost-benefit studies are required. The influence on market competitiveness, possible income streams, and the long-term economic feasibility of the integrated solutions are some of the things that should be taken into consideration. The collaboration of market operators, transmission system operators (TSOs), and regulatory agencies is required for the integration of FACTS and HVDC technologies. The laws of the market and the operational procedures need to be modified so that they can accept the capabilities of these new technologies. This ensured that there is fair competition, efficient dispatch, and good coordination of the regulation of power flow. The selection of suitable FACTS and HVDC technologies based on system needs is one example of a technical problem. Other technical obstacles include the development of improved control algorithms and the compatibility of various devices and systems. In order to guarantee the smooth integration and efficient operation of FACTS and HVDC technologies, it is essential to make sure that compatibility problems, harmonization of control techniques, and standardization measures are taken.

Figure 3 HVDC technologies in deregulated electricity

The effective integration of FACTS and HVDC technologies in deregulated electricity systems has been shown by a number of case studies and real-world instances, including the following: In order to improve grid stability, control power flow, and provide assistance for the integration of renewable energy sources, the California system makes use of FACTS devices such as SVCs and HVDC connections. These technologies have assisted in resolving concerns with voltage stability and have contributed to an improvement in the grid's overall dependability. The Nordic power market includes integrated HVDC lines, which allow for electricity to be exchanged across various nations and help maximize the use of renewable energy resources. HVDC lines provide for effective transmission of electricity over vast distances, as well as load balancing and more flexibility in power trading. In order to enhance power quality, manage voltage levels, and reduce grid fluctuations, the power grid in India has installed FACTS devices, including STATCOMs. The integration of these devices has resulted in improvements to the performance of the grid as well as the stability of the system. The integration of FACTS and HVDC technologies in deregulated power systems provides a number of advantages, some of which include greater control over the flow of electricity, increased grid dependability, and the incorporation of alternative forms of energy. However, in order to guarantee that the implementation is effective, it is necessary to address difficulties relating to the cost, the functioning of the market, and technological factors. The combination of FACTS with HVDC has been shown to be useful in increasing the performance of power systems, as shown by case studies and examples from the real world. The continuation of research and development efforts, as well as cooperation among many stakeholders, further accelerate the integration of these technologies and pave the way for a deregulated electricity system that is both more efficient and more robust.

Voltage stability is maintained by the strategic use of reactive power control devices like capacitors, reactors, and FACTS devices (e.g., SVCs, STATCOMs). Examples of these devices are capacitors and reactors. Automatic Voltage Regulators, often known as AVRs, are used frequently in the process of regulating the terminal voltage of generators and ensuring the stability of voltage. AVRs constantly monitor the voltage of the system and make adjustments to the field excitation of generators in order to keep the voltage levels at the appropriate levels. LTCs are used in transformers to achieve voltage regulation at the load end of the device. LTCs contribute to the maintenance of voltage stability by compensating for voltage decreases or increases via the modification of the turns ratio of the transformer. Another essential component of system stability is frequency stability, which involves ensuring that the system frequency stays within a range that is considered to be acceptable. Stability of frequency is very necessary for the continued synchronization of generators, the maintenance of load balance, and the successful functioning of power system equipment. In order to get greater frequency stability, the following strategies are utilized: The frequency of the system is continually monitored by AGC systems, which then regulate the output of generators to keep the frequency stable within a certain range. AGC systems make use of control algorithms and feedback mechanisms to guarantee that the load is evenly distributed and that the power production is done correctly. Primary frequency control, which is often referred to as droop control, is implemented at individual producing units to enable them to automatically alter the amount of power they produce in response to variations in frequency.



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Additional frequency regulation is provided by secondary frequency control, which is carried out by automatic generator control (AGC) systems. This regulation is accomplished by coordinating the power output of various generators. In the case that the frequency drops significantly, UFLS designs are intended to shed a certain amount of load as quickly as possible. By lowering the load demand and restoring frequency stability, UFLS contributes to the prevention of a blackout affecting the whole system. The capacity of the power system to retain synchronism and recover from disturbances such as faults and unexpected changes in load or generation is ensured by dynamic stability. Dynamic stability also guarantees that the power system can maintain synchronism. Several different steps are made in order to improve the dynamic stability: Synchronous generators often have PSS devices put in them so that the generators' damping properties may be improved and system oscillations can be stabilized. PSS devices are responsible for detecting oscillations and sending the necessary control signals to the excitation system of the generator.

Conclusion

The integration of High-Voltage Direct Current (HVDC) systems and Flexible AC Transmission System (FACTS) devices in power systems offers numerous benefits and improvements in voltage profiles, active power transfer, and transient stability. This research article has explored the role of FACTS devices and HVDC connections in enhancing voltage regulation, power transfer efficiency, and system damping characteristics. The findings of this study highlight the significant impact of FACTS devices and HVDC technologies on power system performance. The integration of FACTS devices, such as SVCs and STATCOMs, enables dynamic control of voltage, impedance, and phase angle, resulting in improved power flow management, voltage stability, and transient stability. HVDC systems, on the other hand, facilitate efficient long-distance transmission of bulk power and the integration of renewable energy sources.

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