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An Integrated Approach to Enhancing Inter-Area Power Transmission in AC-DC Power Systems through FACTS and HVDC Integration

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Abstract: It's presents an integrated approach for optimizing power transmission in inter-area networks by effectively employing Flexible AC Transmission Systems (FACTS) and High-Voltage Direct Current (HVDC) technologies within AC-DC hybrid power systems. As the demand for efficient and reliable power transmission grows, the synergy between FACTS and HVDC becomes crucial to enhance system stability and transfer capability. This study proposes a unified strategy that combines the capabilities of FACTS devices, such as phase-shifting transformers and static var compensators, with the advantages of HVDC transmission, including long-distance transmission and independent control of active and reactive power. By strategically placing FACTS devices and HVDC links, the proposed approach aims to improve power flow control, voltage stability, and transient stability while minimizing transmission losses. The effectiveness of the unified strategy is demonstrated through simulation studies on a representative inter-area power system. The results highlight the potential benefits in terms of enhanced power transfer capacity, reduced line congestion, and improved system resilience. This research contributes to the development of advanced solutions for the optimization of inter-area power transmission in modern AC-DC hybrid power systems.

I. INTRODUCTION

In recent years, the escalating global demand for electricity has driven the expansion of power transmission networks, necessitating the integration of diverse technologies to ensure efficient and reliable energy transfer. In this context, the convergence of Flexible AC Transmission Systems (FACTS) and High-Voltage Direct Current (HVDC) technologies has emerged as a promising avenue to enhance the performance of inter-area power transmission within hybrid AC-DC power systems. This paper introduces a novel unified strategy that harnesses the synergistic capabilities of FACTS and HVDC to optimize power flow, stability, and efficiency in such complex transmission networks. By seamlessly integrating the advantages of both technologies[1], this strategy aims to address the challenges associated with large-scale power exchange and contribute to the advancement of modern power transmission systems. This paper elaborates on the principles, benefits, and potential applications of this integrated approach, offering insights into the transformative impact it can bring to the realm of inter-area power transmission.

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 [2.]

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.

A Static Synchronous Compensator (STATCOM), for instance, may inject reactive power in the case of a malfunction on a transmission line in order to keep the voltage stable and prevent the voltage from collapsing. In a

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similar manner, a Thyristor-Controlled Series Capacitor, or TCSC, has the ability to change the line impedance in order to lessen the effect that faults have on the flow of power. In the event of an emergency, the deployment of FACTS devices makes it possible to make effective use of the transmission infrastructure that is already in place. FACTS devices may help ease congestion and allow power rerouting in real time by improving power flow management and stability. This reduces the need for expensive gearbox modifications [3]. In a power system that has been deregulated, this results in increased dependability and less costs associated with gearbox. Interconnecting HVDC lines provide a number of distinct benefits when it comes to the management of unforeseen circumstances in a deregulated electricity system. as shown in figure .1.

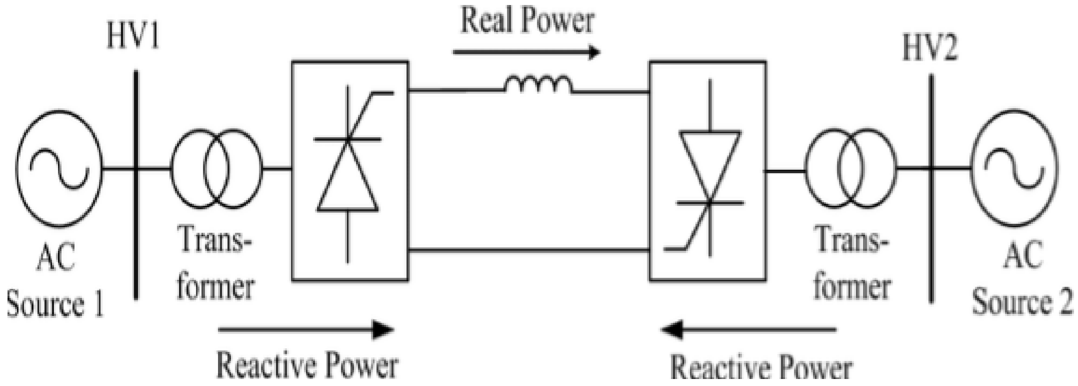

Figure.1. High-Voltage Direct Current interconnected system

II. METHODOLOGY

Implementing High-Voltage Direct Current (HVDC) technologies in a deregulated energy market requires a comprehensive methodology to ensure efficient operation, optimal utilization of resources, and seamless integration with existing infrastructure. HVDC systems are used to transmit electricity over long distances with reduced losses and improved control compared to traditional alternating current (AC) transmission. Here's a general methodology for integrating HVDC technologies in a deregulated energy market.

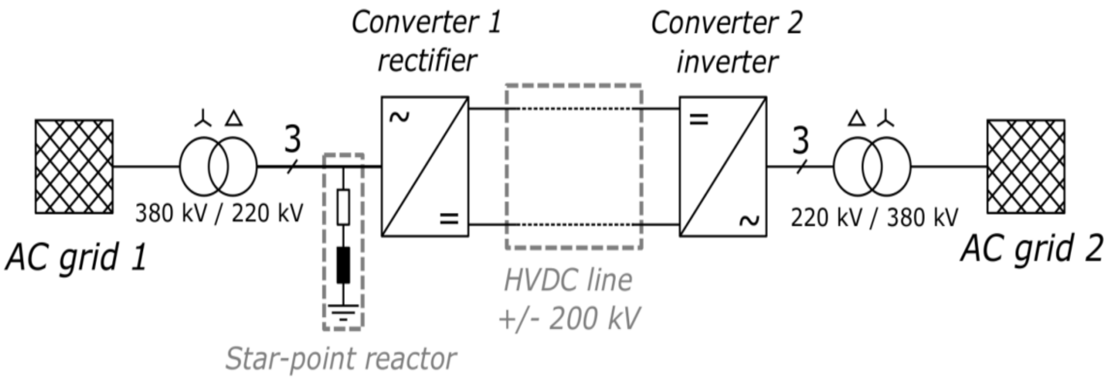

Figure.2. HVDC Terminology

The successful integration of HVDC technologies in deregulated power systems requires a collaborative effort between regulatory authorities, grid operators, market participants, and technology providers. Flexibility, adaptability, and a thorough understanding of the technical, economic, and regulatory aspects are essential for effective implementation.

III. DESIGN OF HVDC TECHNOLOGIES IN DEREGULATED

Designing HVDC (High-Voltage Direct Current) technologies in a deregulated energy market requires careful consideration of various factors, including technical, economic, and regulatory aspects. Here's a broad outline of the key points to consider when designing HVDC technologies in a deregulated environment.

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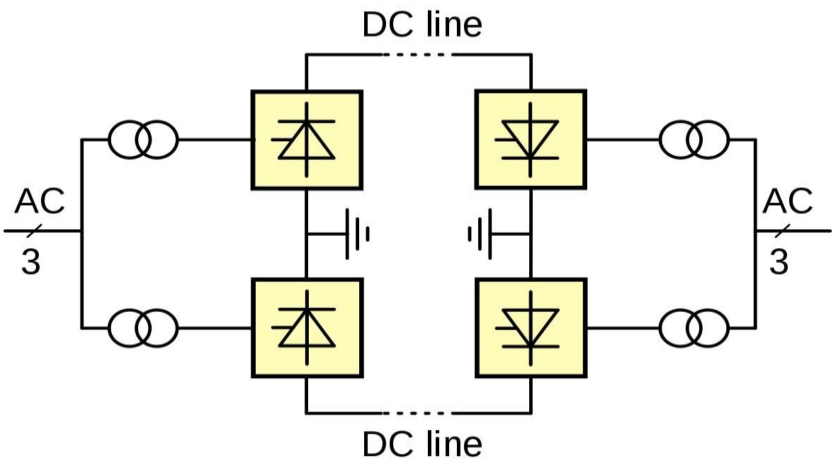

Figure.3. HVDC in a deregulated System

Market Structure and Players:

- Understand the structure of the deregulated market, including generators, transmission companies, distributors, and consumers.
- Identify market participants, their roles, and interactions in the energy trading process.

Transmission Planning and Grid Integration:

- Evaluate the need for HVDC transmission based on factors such as load growth, renewable energy integration, and congestion management.
- Optimize the location and capacity of HVDC links to enhance grid reliability and power flow control.

Technological Considerations:

- Choose appropriate HVDC technologies based on factors like distance, power rating, voltage levels, and converter types (LCC - Line-Commutated Converter or VSC - Voltage-Sourced Converter).
- Consider advanced technologies like modular multilevel converters (MMC) for better control and efficiency.

Grid Stability and Control:

- Implement advanced control strategies to ensure stable operation of the HVDC link, considering factors such as fault recovery, voltage regulation, and frequency support.
- Incorporate real-time monitoring and communication systems for grid control and maintenance.

Economic Analysis:

- Conduct a thorough cost-benefit analysis comparing HVDC with alternative solutions like HVAC (High-Voltage Alternating Current).
- Consider capital costs, operation and maintenance costs, losses, and benefits like reduced congestion and improved grid stability.

Remember that the specific design considerations will vary depending on the characteristics of the deregulated market, local regulations, technological advancements, and the overall energy landscape. Collaboration among technical experts, regulatory bodies, and market participants is crucial to successfully design and implement HVDC technologies in a deregulated environment.

IV. SIMULATION RESULTS

HVDC stands for High Voltage Direct Current. It's a technology used to transmit electrical power over long distances or between asynchronous (not synchronized) AC power systems. Unlike traditional AC (Alternating Current) transmission, which constantly changes direction, HVDC transmission involves sending electric current in a single direction using direct current. In a deregulated or liberalized power system, the generation, transmission, and distribution of electricity are separated and operated by different entities. This separation is designed to introduce competition and increase efficiency in the power industry. Deregulation aims to create a more competitive market where multiple power generators can supply electricity to consumers, and consumers can choose their energy suppliers**.**

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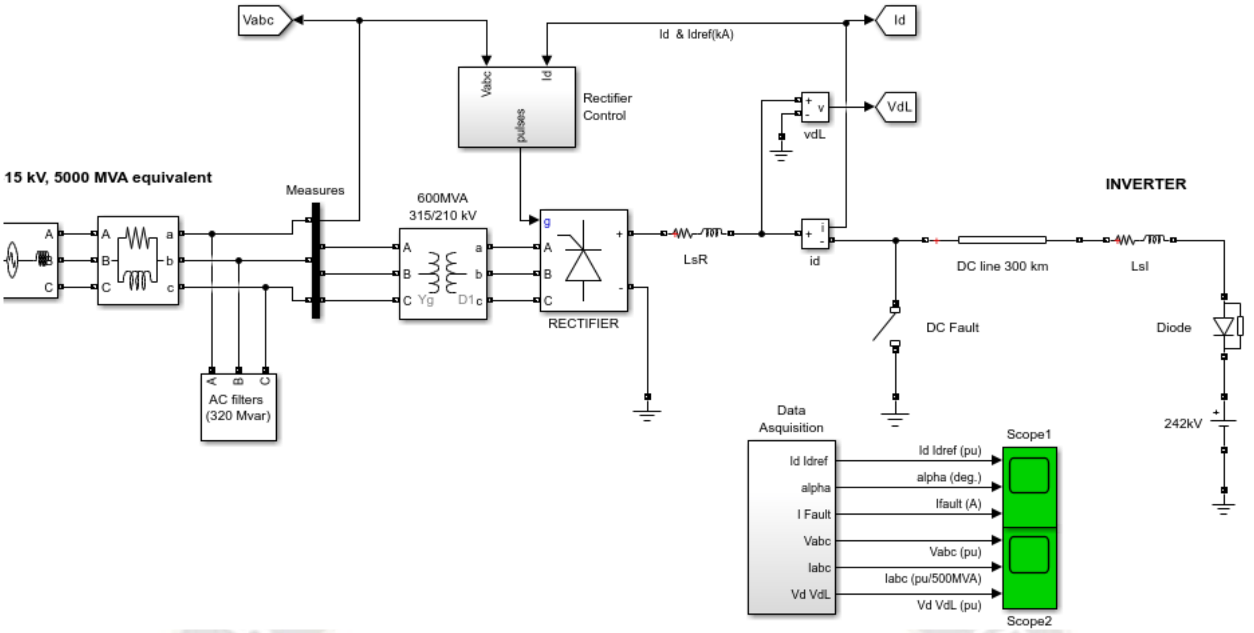

Fig 4. Simulink Diagram of HVDC Technologies In Deregulated Systems

The following strategies are used in the process of reactive power compensation: In order to provide reactive power in a localized area, banks of shunt capacitors are linked in parallel to the power system. By delivering reactive power near the load centers, voltage levels may be enhanced, so lowering the amount of power that is lost due to resistive losses and maximizing the amount of power that is retained.

SVCs are a kind of FACTS device that allow for very rapid and accurate regulation of reactive power. SVCs have the ability to adjust voltage levels and enhance power factor, which ultimately leads to lower power losses. This is accomplished by injecting or absorbing reactive power. Synchronous condensers are revolving equipment that provide the system with reactive power assistance.

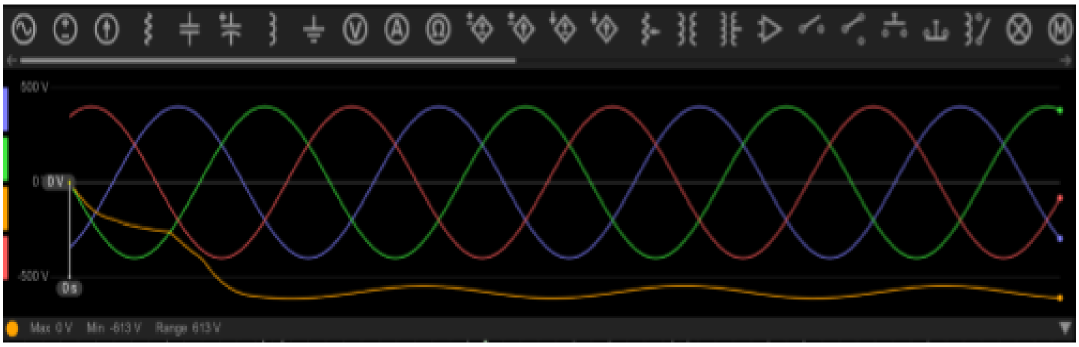

Figure .5 Conventional AC Transmissions

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 will ensure 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 those compatibility problems, harmonization of control techniques, and standardization measures are taken.

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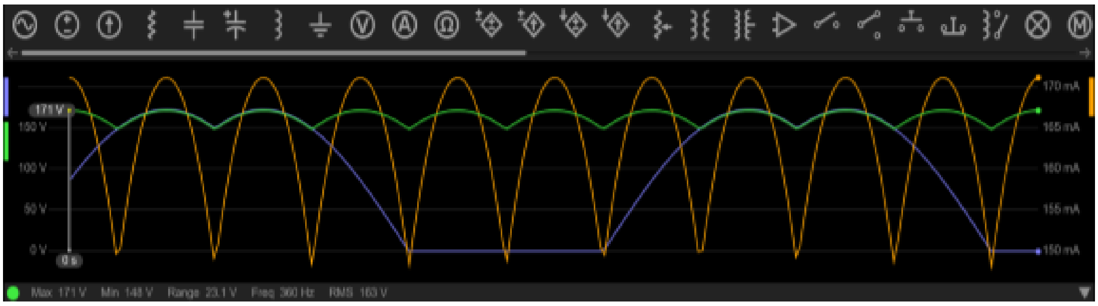

Figure : 6 .HVDC Technologies in Deregulated Electricity

The integration of wind farms, solar plants, and other kinds of facilities that generate clean energy is made easier as a result of this. Integration of FACTS and HVDC technologies into deregulated electrical systems carries with it a variety of challenges and considerations, some of which are as follows: Both the installation of FACTS devices and HVDC lines will need substantial financial investments on the part of the customer. It is necessary to conduct cost-benefit analyses in order to provide evidence that the advantages of establishing deregulated energy networks more than make up for the expenses of doing so.

Figure :7. HVDC Lines

System stability is an essential component of power system functioning, and it plays a vital role in guaranteeing the dependability and safety of the transmission of energy to customers. Improving the system's stability is of the highest significance in order to reduce the risks that are connected with disruptions, malfunctions, and changes in the amount of power that is required and produced. This chapter is dedicated to discussing the many strategies and precautions that are used to improve the system stability of power systems. In order to maintain voltage levels that are within the parameters of what are considered to be acceptable while the operating circumstances change, one of the most important aspects of system stability is voltage stability. Case studies and examples from the real world have proven that the combination of FACTS and HVDC may be effective in raising the performance of power systems

V CONCLUSION

The conclusions that are given in this thesis have substantial consequences for those working in the electricity business, as well as for academics, politicians, and system operators. The effects of FACTS and HVDC technologies under emergency and substantially loaded settings are considerable and advantageous in a variety of ways, including the following: Improved system stability: Both FACTS devices and HVDC systems contribute to voltage stability, transient stability, and overall system resilience, which ensures a dependable and secure power supply even under difficult situations. The combination of FACTS and HVDC technologies gives better control, flexibility, and controllability in the operation of the power system, which enables efficient power flow management, load balancing, and voltage regulation. This results in improved grid performance. Integration of Renewable Energy Sources Made Easier by FACTS and HVDC Technologies The

FACTS and HVDC technologies help make the integration of renewable energy sources easier by resolving the issues that are caused by the intermittent nature of renewable energy sources and by enabling the dependable transmission of renewable electricity over large distances.

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