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FUZZY LOGIC CONTROL STRATEGIES FOR ENHANCED POWER QUALITY IN MMC-HVDC SYSTEMS

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Abstract— **In this proposed PI balancing method, the sub-module capacitor voltage of modular multilevel converter (MMC) is applied to one of the applications, HVDC power transmission i.e. MMC-VSC-HVDC. The proposed PI control strategy provides a useful and economical way to transmit electrical power over a long distance. MMC-based VSC-HVDC has lesser power losses, excellent harmonic performance without the need for any filter or PWM technique and carries continuous current in all converter valves. The dynamic performance and stability of the MMC-based VSC-HVDC transmission system increased by using the FUZZY logic controller technique. Both the control techniques of the HVDC transmission system are simulated by using the MATLAB SIMULINK software.**

Keywords: **Modular multilevel converter (MMC), VSC converter, HVDC transmission system, MATLAB SIMULINK.**

INTRODUCTION

Most of the world's electric power systems remain connected for cost reduction and increased dependability. Interconnections make use of the variety of loads, the availability of sources, and the cost of fuel to provide electricity to loads with the least amount of expense and pollution while maintaining essential reliability. An efficient electric grid is critical to the competitive climate of dependable electrical service in a deregulated electric service environment [1].

A power system is intended to function across a wide range of conditions, including no load, overloading, and short circuits. It is desired that the quality of supply be maintained under all circumstances, i.e., the constancy of voltage magnitude and system frequency. Additionally, it's ideal to keep the three-phase currents and voltages at as balanced as feasible to prevent excessive heating of various rotating devices owing to imbalance. The transmission network is currently under more pressure than ever, and this pressure will only continue to grow as nonutility sources proliferate and utilities themselves become more competitive. New rights of way are not simple to get. Less security and lower quality of supply have been the results of increased demands on transmission, a lack of long-term planning, and the requirement to grant open access to producing businesses and customers. Therefore, compensation in power systems is crucial to resolving some of these issues. For many years, series/shunt compensation has been used to accomplish this goal.

The regulation of reactive power, particularly the voltage and P.F. levels, is known as load compensation. Here, a specific load is considered when adjusting the reactive power, and the load itself is coupled to the compensating device. The three main goals of load compensation are as follows. (i). an improved voltage profile. (ii). Correction, P.F. (iii). Balanced load.

It is common knowledge that a series impedance carrying a load current I have the following approximate p.u. voltage regulation:

$$\Delta V = \frac{IR}{v}\cos\phi + \frac{IX}{v}\sin\phi$$

where V is the load voltage and ϕ is the load's p.f. angle. Positive here indicates an inductive load, and negative indicates a capacitive load. By placing a capacitance across an inductive load, the load can be effectively rendered capacitive. This allows for the adjustment of capacitance values to the point where they are equal and the change in load voltage is equal to zero. Therefore, supply voltage differences brought on by changes in the load's actual and reactive power can be completely eliminated by a solely reactive compensator. The fundamental needs of a power system are system stability and voltage levels. By stability, we indicate the power system's propensity to continue running even when the system is subjected to a fault, a sudden change in load, or any other external factor that may have a tendency to make the system unstable, the intended mode (voltage and frequency to remain within acceptable limits). It is a measure of creating restoring forces inside the system to balance the disturbing forces, such as short circuits or an increase in loads, etc. It is an inherent attribute of the system, just like any other system. Various power system components exchange power or energy when there are disturbances. Different synchronous machines can only operate and deliver or absorb energy at synchronous speeds (during normal operation) or just slightly faster (during a brief period of disruption) [2].

The functionality of the power system is seriously threatened by the transmission of energy from generating stations to outlying places. Bulk power transmission over a long distance by overhead transmission line and undersea cable is required to address the aforementioned issue; however, due to high charging current and losses brought on by capacitance, AC transmission presents difficulties.

Voltage level and frequency are the key factors preventing interconnection through an AC link in the problem of connecting the unsynchronized grids to the existing grid. Using regulated DC transmission, which gives the flexibility for a bulk power transmission over a long distance using a DC link, the aforementioned difficulty can be eliminated. A controlled power flow is made possible by the employment of converter stations at the generating end for AC/DC conversion. Power electronics switches are undergoing rapid development and research, which offers a better, more effective method for controlling mechanisms and, consequently, control over power flow. There are two primary types of converter technology used in HVDC transmission. These are self-commutated voltage-sourced converters (VSCs) and conventional line-commutated current source converters (CSCs) [2].

Thyristor valves were the foundational technology for DC transmission in the 1950s, and line-commutated current source converters are employed in traditional HVDC technology. Because thyristors are not fully controlled switches, the control mechanism for controlled power flow is limited. In 1990, the idea of high-voltage direct current (VSC-HVDC) based on voltage source converters was first put out. Because voltage source converter-based transmission technology uses fully programmable switches like IGBT, one of the most effective control mechanisms for controlling power flow, it introduces flexibility in power transmission.

For applications including long-distance transmission, subterranean and submarine cable transmission, and the linking of asynchronous networks, both conventional and VSC-HVDC are used. However, from a control perspective, VSC-HVDC is more adaptable and has a more effective power flow mechanism since it can separately control active and reactive power to maintain a constant voltage and frequency. VSC transmission technology, in particular self-commutation, dynamic voltage management, and black start capability, enables the provision of isolated loads on islands via long-distance submarine cables. Pulse width modulation, self-turn-off devices.

VSC is the foundation of the VSC-HVDC technology. Back-to-back voltage-sourced converters (VSCs), a common DC connection made up of big DC capacitors and DC cables, and a high-voltage direct current (HVDC) link make up the VSC-HVDC link. Controlling the DC side voltage of one converter while another converter controls the active power is how the control approach achieves coordination of the active power control between two stations. Constant DC voltage from a source known as the "slack bus" allows for automatic management of power flow between stations. Reactive power control and AC voltage control will swap depending on the situation.

PROPOSED MODEL

1. PI Controller:

Forced oscillations and steady-state error, which are responsible for an on-off controller and P controller operation, will be eliminated by the PI controller. Integral mode, however, has a negative impact on the system's overall stability and response time.

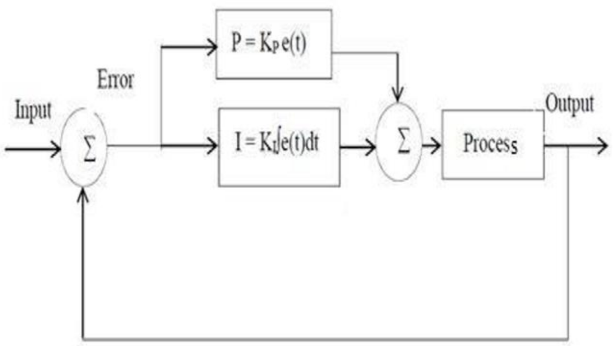


Fig.1. Block diagram of PI controller.

The controller output in this case is

$$u(t) = K_p e(t) + K_i \int e(t)$$

As a result, the PI controller won't accelerate the reaction time. Since the PI controller lacks the ability to foresee what would happen with the error in the near future, it is to be expected. Derivative mode, which may predict what will happen with the mistake in the near future and minimize a controller's reaction time, can be included to address this issue.

1. Fuzzy Logic Controller:

Fuzzification, the initial procedure to be carried out, entails converting the FLC's input and output ranges into the matching Universe Of Discourses (UOD). The second step is to split up the various inputs into appropriate linguistic variables. The Membership Functions (MF) shape affects the fuzzification module's parameters.

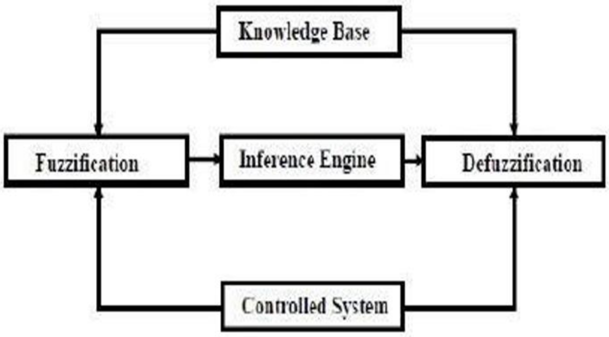


Fig.2. The basic structure of Fuzzy Logic Controller.

Fig.2. shows the basic structure of the Fuzzy Logic Controller.

There are four principalelements to a fuzzy logic controller:

a) Fuzzification module (Fuzzifier).

b) Inference mechanism.

c) Knowledge base.

d) Defuzzification module (Defuzzifier).

a). Fuzzification module (Fuzzifier):

The first step in designing a fuzzy controller is to decide which start variables representing the system dynamic performance must be taken as the input signal to the controller. Fuzzy logic uses linguistic variables instead of numerical variables. The process of converting numerical variables (real numbers or crisp variables) into linguistic variables (fuzzy numbers) is called fuzzification. System variables, which are usually used as the fuzzy controller inputs include state error, state error derivative, state error integral etc.

b). Inference mechanism:

FLC design must consider interface mechanisms carefully. The firing strength of each rule is calculated by adding the membership values acquired in the fuzzification stage. By using a set of linguistic control rules, each rule characterizes the control objective and control strategy of the domain experts. Then the corresponding component of each qualified rule is formed based on the firing strength. the following are the most popular interaction mechanisms:

a. Mamdani type.

b. Takagi-Sugeno type.

c). Knowledge base:

The knowledge base of an FLC consists of a database whose primary purpose is to offer the data required for the appropriate operation of the fuzzification module, the inference engine, and the de-fuzzification module. The required details consist of The linguistic meaning of the process state and control output variables represented by fuzzy sets (membership). Physical domains, their normalized counterparts, and the scaling (normalization) factors.

d). Defuzzification module (Defuzzifier):

Defuzzification is the opposite of fuzzification. In fuzzy logic controller usage, the necessary output is generated in a linguistic variable (fuzzy number). The linguistic variables must be transformed into crisp output in accordance with real-world needs. The centre of gravity approach was employed in this study.

Characteristics of Fuzzy Logic Controller (FLC):

One of the key benefits of employing fuzzy control can often be categorized as robust non-linear control. A noteworthy aspect of fuzzy logic controllers is their tendency to have a nonlinear transfer function..

A significant parameter changes for a significant external disturbance for the traditional PI controllers. A typical PI controller fails in the presence of such a disruption. In this situation, a fuzzy controller proposes to put into practice straightforward yet reliable solutions that can convert a wide variety of system parameters and handle significant disruptions. Putting expert knowledge into practice: One way to do this is through fuzzy control.

RESULTS AND DISCUSSION

In this chapter of the book, we delve into the results and analysis of the power system's integration with MMC VSC-HVDC, employing a power compensation control system based on fuzzy logic. The chapter includes the presentation of results achieved with both PI and fuzzy controllers. Throughout this discussion, we leverage mathematical computation functions, system simulation techniques, and practical application development. The high-performance and multifaceted MATLAB/SIMULINK software platform plays a pivotal role in our investigations.

One of the design tools for simulating and modelling electric power systems in the SIMULINK environment is the power system block set. It includes a block library of typical electrical power network elements and gadgets based on electromagnetic and electromechanical equations. Power and control system modelling and simulation can be done with PSB/SIMULINK. PSB uses either a fixed or variable integration time step to solve the system equations through the state variable analysis. Continuous or discrete domain state equations are used to express the system's linear dynamics.

Schematic diagram of Back-to-Back MMC-based VSC-HVDC system:

The system is made up of a three-phase source with a 420 KV, 1250 MW capacity, interconnected AC networks, and connected PI and FUZZY controllers, which offer a high level of power outage difficulties and consistent voltage at the load side. It is made up of two AC systems that are joined back to back using a DC link. In MATLAB, the MMC-HVDC system with PI controller is simulated.

Dynamic Performance:

Comparing the dynamic responsiveness of the MMC-HVDC system with and without the PI controller Moreover, two cases are examined. The active power reference, shown in Fig. 5, steps to 0.1p.u from zero. The reference U* steps from 1.0p.u to 1.1p.u are shown in Fig. 6.

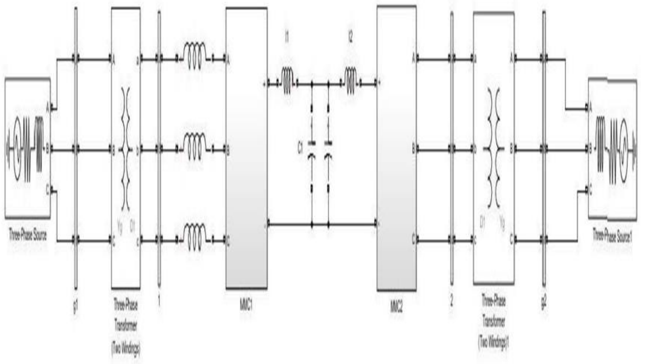


Fig.3. Schematic diagram of Back-to-Back MMC-based VSC-HVDC system.

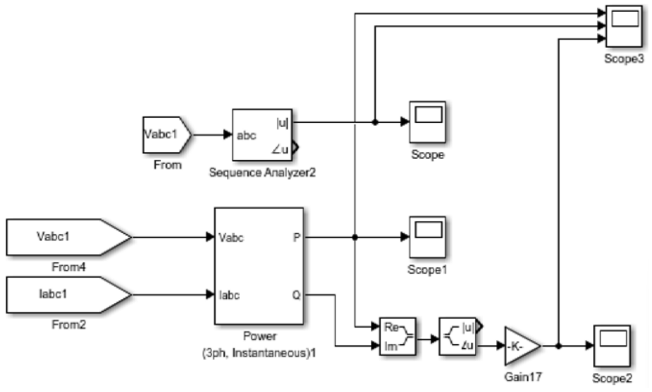


Fig.4. Simulink model of the scope of Active power, Pcc voltage, Phase angle ð.

Stability and Damping Performance Analysis:

By using the electromagnetic simulation model's setups, the stability performance is examined. For both methods, the active power reference P* is obtained from the dispatching centre steps -0.1 p.u. every 0.5s. Kpac = 0.005 and Kiac = 0.05 are chosen as the PI regulator's parameters, and the associated waveforms are shown as shown in Fig. 7. Kpac = 0.035 and Kiac = 0.35 are chosen as the PI regulator's parameters, and the related waveforms are shown as shown in fig. 7. However, this technique of compensatory strategy exhibits satisfactory performance, maintaining a nearly constant PCC voltage throughout the dynamic process. In Fig. 8, the waveforms are displayed.

This section simulates the damping performance of this method to demonstrate that the system cannot be operated steadily by using a single virtual impedance active damping method. We tested two cases. The first one is the accelerating instability (P*=-1.04 p.u.). The second one involves oscillatory instability (P*=0.94 p.u.). The matching waveforms (P, Us,) are plotted in Figure 9. The red line shows that the proposed approach was initially disabled at t=1.05 seconds for the first example and at t=4 seconds for the second case. The blue line shows that, for the first example, the proposed method is re-enabled at t=1.15s, and for the second case, at t=6s. The simulated waveforms show that the system remains stable as long as

Fault Ride through Capability:

Between t=2 and t=2.4s, a single-phase grounding fault (SPGF) at the PCC is simulated. In Fig. 10, the simulated waveforms are depicted. P and Q both fluctuate with twice-fundamental frequency throughout the SPGF phase. After the fault is fixed, P and Q both gradually resume operation. The PPS and NPS voltages are typically 1 and 0 p.u. in the balanced condition, respectively. However, there exist PPS and NPS voltages in the three-phase voltages when an imbalanced fault, such as an SPGF, occurs. Qref is capped at -0.4p.u to prevent overvoltage on the non-fault phases.

Voltages of the non-fault phases can exceed 1.28p.u. under this circumstance. If the limit is not established, non-fault phases will experience additional overvoltage. In the third Section, the curve is sketched. The angle difference does not fluctuate during the SPGF time, and after the fault is cleared, it returns to a steady state. The related electromagnetic transient models are built in the MATLAB/Simulink environment to verify the method's efficacy. Intentionally, the SCR of the Chongqing side simulation model has been set to 1. Other parameters are the same as the intended project, with the exception of SCR and Cf on the Chongqing side. The Hubei side station controls the DC voltage.

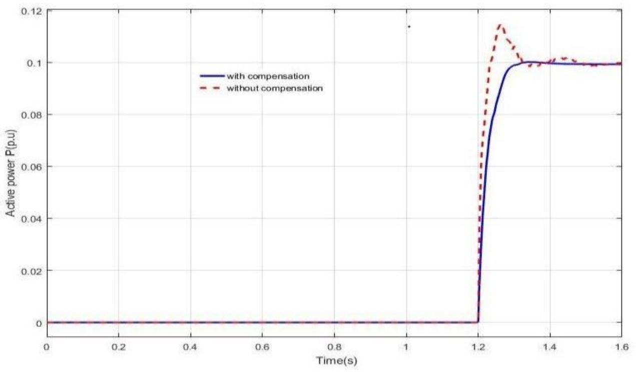


Fig.5. Active Power Steps to 0.1p.u with and without compensation.

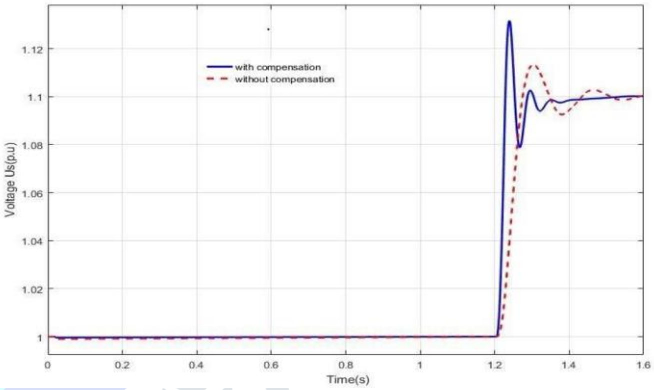


Fig.6. PCC Voltage Steps to 0.1p.u with and without compensation.

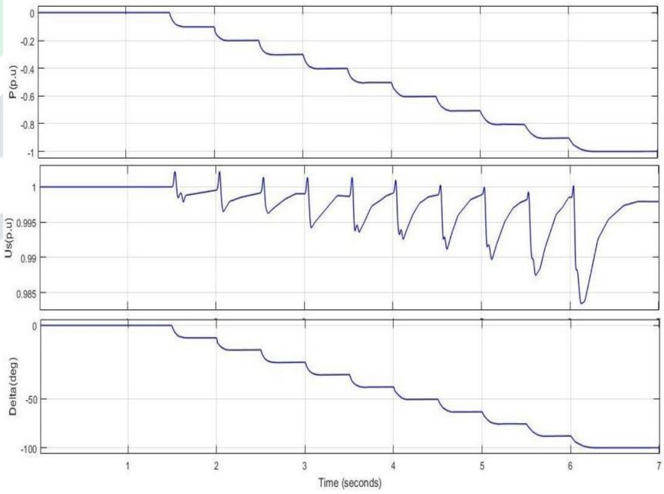


Fig.7. Stability performance of the system when K_{pac} = 0.005, K_{iac} = 0.05.

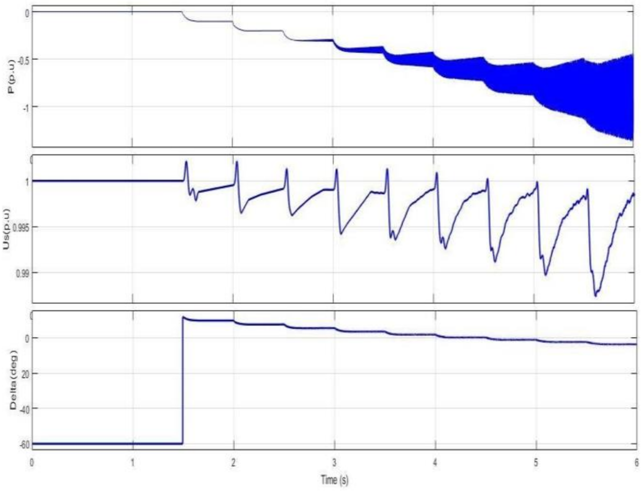


Fig.8. Stability performance of the system when K_{pac}= 0.035, K_{iac} = 0.35.

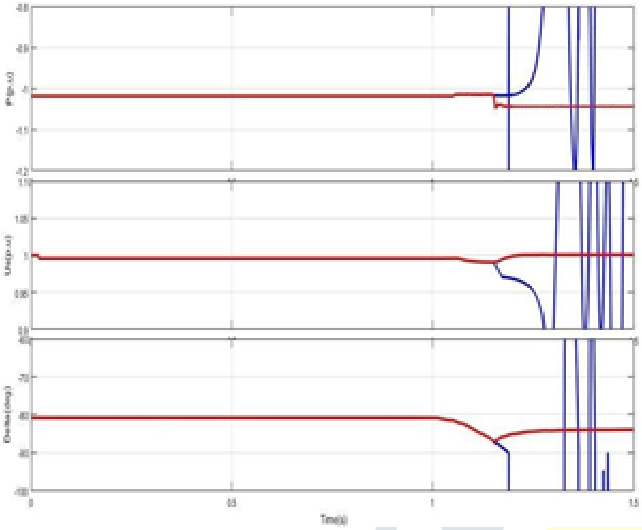
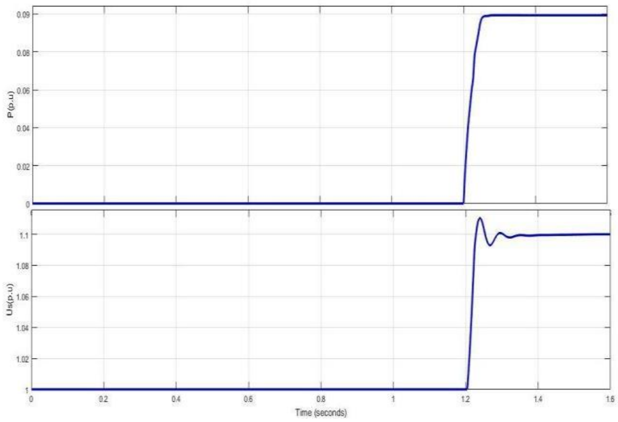


Fig.9. Dynamic Performance of the system for the step value of P= -1.04p.u.



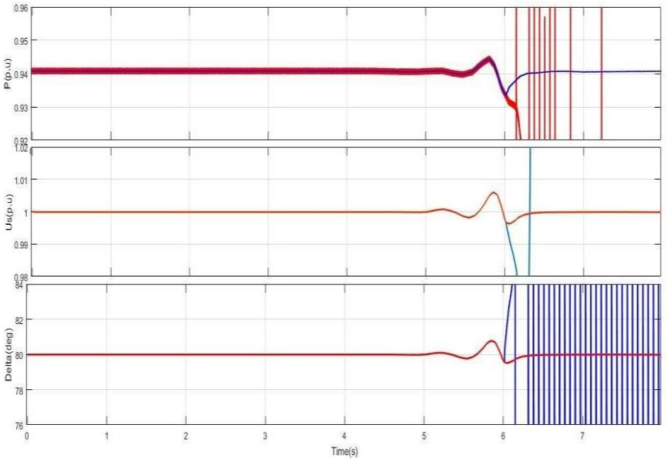


Fig.10. Dynamic Performance of the system for the step value of P= 0.94p.u.

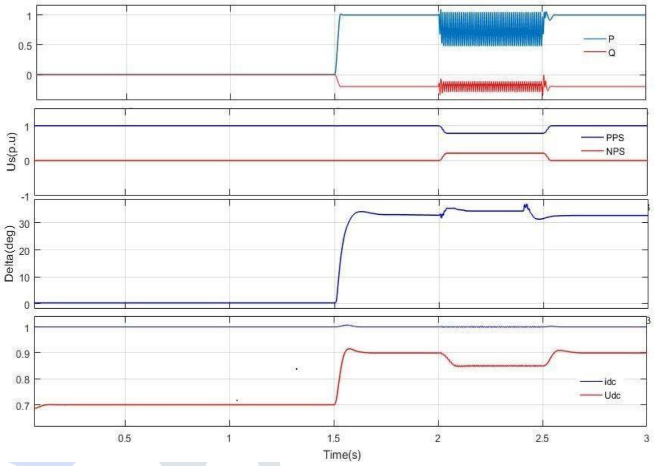


Fig.11. Fault Ride through performance.

MMC- HVDC system with FUZZY logic controller:

A suggested technique uses a VSC-HVDC system with a FUZZY logic controller, and the waveforms are simulated in MATLAB/Simulink. The dynamic performance of the suggested technique with the FUZZY controller is shown in the waveform in Fig. 11. For a step voltage of 0.1p.u., a graph is drawn between active power, PCC voltage in p.u., and time in seconds. The stability performance waveform of the suggested technique with the FUZZY controller is shown in Fig. 12. As a result, the instability is getting worse. With the PCC voltage being essentially constant during the dynamic process, the suggested technique exhibits satisfactory performance. The waveforms of the suggested method's damping performance with the FUZZY controller are shown in Fig. 13. When a step voltage of -1.04p.u. is used, a graph between Active power, PCC voltage, Phase angle, and time shows accelerating instability. Fig.14 displays the Phase angle and time which gives oscillatory instability when a step voltage of 0.94p.u.

Fig.12. PCC Voltage and active power for a step change of 0.1 pu

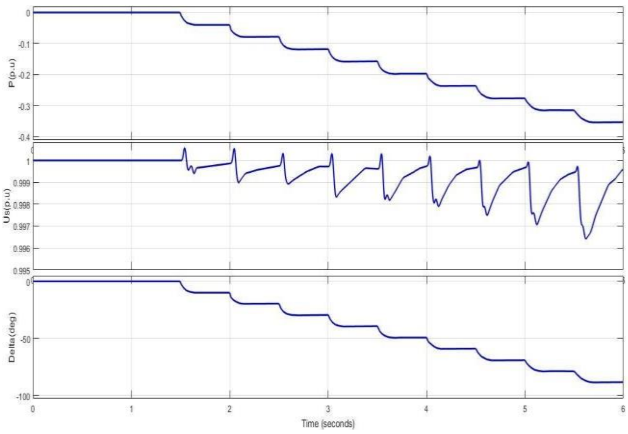


Fig.13. Stability Performance of system when K_{pac} = 0.005, K_{iac} = 0.05 with fuzzycontroller.

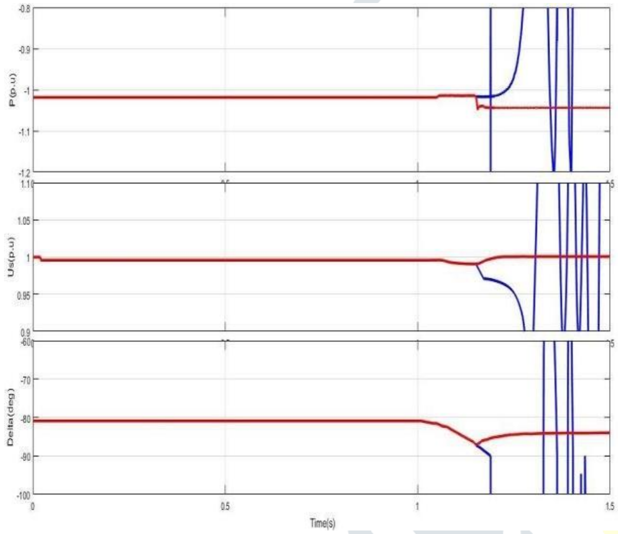


Fig.14. Damping performance analysis of the proposed method for a step change of P= -1.04p.u with the fuzzy controller.

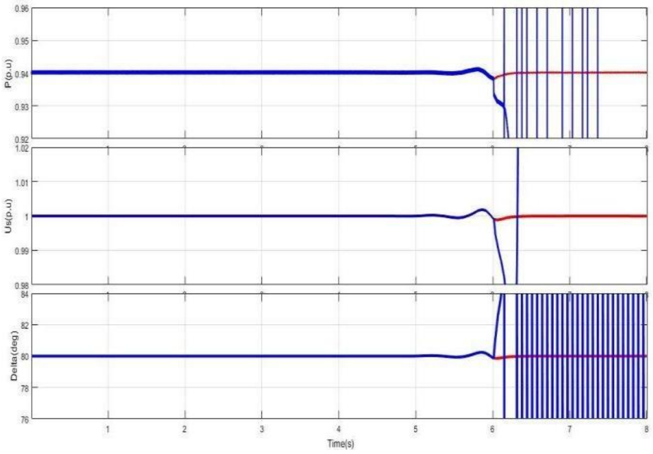
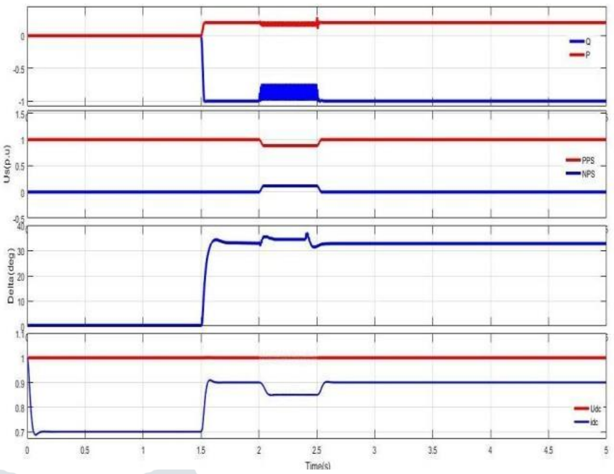


Fig .15. Damping performance of the proposed method when step of -0.94pu with fuzzycontroller

Fig.16. Fault ride-through performance of the proposed method with the fuzzy controller.



CONCLUSION

In this publication, the study proposes a compensatory MMC-based VSC HVDC system. A PI controller, fuzzy membership function tuning, and an ideal fuzzy rule basis are used to tune the controller parameters to their ideal values. The parameters for the conventional PI controllers change significantly with a major external disruption. In the presence of such a disruption, a standard PI controller malfunctions. A fuzzy controller suggests using simple, dependable solutions that can convert a wide variety of system parameters and resist substantial interruptions in this case. The fuzzy controller compensation approach based on the tiny signal model of the integrated system has been used to examine the effects of compensation coefficients and steady-state operating points on system performance. The response time of the active power loop can be on par with that of the AC voltage control loop. The viability and effectiveness of the suggested control have been established by analysis of the dynamic performance, operational constraints, disturbance rejection capabilities, and fault ride-through capability of the Back-to-Back VSC-HVDC system.

FUTURE SCOPE:

VSC-HVDC technology is being developed in order to boost cost-effectiveness and transmit large amounts of power. The SCR of the AC system is no longer a limiting factor for VSC-HVDC links linked to weak AC systems thanks to VSC-HVDC regulation. SCR variation, or model uncertainty, is still a problem, though. Other options for addressing model uncertainty include In the thesis' linear models, the losses of the VSC valves were overlooked. Frequency-scanning results, however, demonstrated the significance of including valve losses in linear models if DC resonances are a concern. The converter's topology needs to be considered in the linear model in order to accurately depict the valve losses.

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