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ENHANCEMENT OF POWER AND STABILITY OF HVDC TRANSMISSION SYSTEM BY USING INTELLIGENT CONTROLLERS

Engineering

Prabhakara Sharma.P * — Associate Professor, Department of Electrical & Electronics Engineering, Kallam Haranadhareddy Institute of Technology (A), Chowdavaram, Guntur, Andhra Pradesh, India. *Corresponding Author

P. Kanta Rao — Professor, Department of Electrical & Electronics Engineering, SRKR Engineering College (A), Bheemavaram, Andhra Pradesh, India.

K.Vaisakh — Professor, Department of Electrical Engineering, Andhra University College of Engineering (A), Visakhapatnam, Andhra Pradesh, India.

ABSTRACT

A traditional approach to controlling high voltage direct current (HVDC) transmission systems is to use proportional (P) and integral (I) controllers with fixed gains of Kp and Ki, respectively. Although such controllers are robust and simple, they have a number of drawbacks. They are difficult to optimize in order to provide the highest overall performance under all scenarios. Among the many control approaches currently in use in the field of intelligent controllers of the HVDC systems such as fuzzy logic control and artificial neural network based control are the two most widely employed. As the name implies, neuro-fuzzy systems combine artificial neural networks (ANNs) with fuzzy logic into a single system. An intelligent control technique combination has the goal of combining the advantages of both intelligent control approaches while shunting out their respective shortcomings. The CIGRÉ model, as one of the conventional methods, has been studied, and new complementary characteristics have been added in order to improve its power capability and stability during disturbances in high voltage transmission systems, as well as to increase the efficiency of the proposed model. These results were analyzed by using MATLAB/Simulink.

KEYWORDS

HVDC transmission, CIGRÉ Benchmark model, Faults in HVDC system, PI controller, Fuzzy logic controller, Artificial Neural Network controller, ANFIS controller.

I. INTRODUCTION

HVDC transmission is the preferred method for long-distance bulk transmission of power. As a mature technology, an HVDC system has undergone a number of changes in development, from mercury-arc to thyristors to IGBT and IGCT valves, and from basic PI controllers to more sophisticated ones [3]. In order to improve the transmission performance and efficiency of these systems, a lot of work needs to be done on the control parts.

The performance of these systems is regulated by the control method that is employed. Controlling a high-voltage direct current system remains a formidable challenge due to several of factors including changes in system conditions, converter transformer saturation characteristics, the presence of AC/DC filters, and the generation of harmonics by converter units, all of which make the HVDC system highly complex and non-linear [1].

The use of properly-designed neuro-fuzzy logic controllers has been widely shown to provide at least marginal improvement in the operation of HVDC systems compared to the use of conventional constant-parameter PI controllers [2-5]. This is explained by the fact that the tuning of constant-parameter PI controllers is a compromise between the speed of response and stability after small disturbances, and the robustness to tolerate large signal disturbances due to faults.

II. HVDC TEST SYSTEM

The CIGRE benchmark HVDC system model used to compare the performance of various HVDCsystem control strategies, the CIGRE benchmark HVDC system model was utilized as the test system [6].

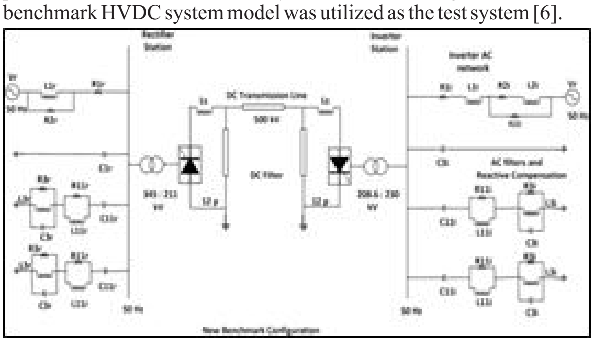

Fig. 1: Single-line diagram of the CIGRÉ benchmark HVDC system.

It is well known that an HVDC converter feeding into a weak AC system is more likely to have commutation failures when it is feeding into a weak AC system. People on both sides also hear it. There's also a DC resonance near the first harmonic frequency and an AC one near the second harmonic frequency. Overall, the system has been made to be very difficult to control with DC power. This makes it a good choice for a test system in HVDC system control studies. The control system must be able to control a quantity like the DC current or the power that is sent or received. It must also be able to keep the system stable even when there are small system disturbances or faults [8].

To achieve these goals while using the least amount of reactive power, the firing angles must be kept as small as possible.There is a constant current (CC) control for the rectifier and a constant extinction angle (CEA) control for the inverter to keep the DC voltage stable. For normal conditions, the CEA control makes sure the extinction angle stays at its nominal value. These results in small reactive power consumption and enough commutation margins to avoid commutation failures. It's common to use the current margin control method in a two-terminal HVDC system. In this case, the rectifier is kept under current control (CC) and the inverter is kept under constant extinction angle (CEA) control. Ie is the difference between the reference current, Id, and the measured current, Id, from the system. It is sent to the PI-controller [7-9].

The controller output is used by the PI gains to get the correct alpha order for the HVDC converter. Because there are a lot of unknowns in the system, it's hard to pick the best gains. The Proportional Integral (PI) controllers are often used in the HVDC system in homes. Adding AI controllers with traditional controller design methods, you need to make a mathematical model of the real plant in order to make the controller. In many cases, it may be hard to find the right parameters for plants that are complex, nonlinear, and change over time. This may make it difficult to fine-tune parameters 10].

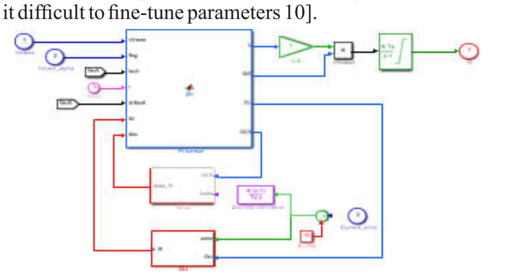

Fig. 2: Structure of PI controller.

Fuzzy logic relies on intuitive rules rather than a precise model to control the system. As a result, Fuzzy Logic is wellsuited to complicated nonlinear systems like HVDC systems. According to research work, the PI Controller parameters may be modified using constant triangular membership functions [11]. It has been shown that fuzzy logic can help reduce commutation failures, improve the margin for error in HVDC, or reduce HVDC oscillations in different situations [12].

III. ARTIFICIAL NEURAL NETWORK AND INFERENCE SYSTEM CONTROLLER (ANFIS)

The neuro fuzzy model configuration with hybrid learning rule to obtain the desired output, FIS uses a predefined mapping of input data. The fuzzy logic operators, membership functions and if-then rules all play a role in this process. It can handle highly non- linear functions and predict the future value of a chaotic time with multiple inputs and a single output [13]. The non-dimensional error index obtained from the ANFIS is better than the capabilities of approaches such as cascaded correlation ANN, back propagation ANN, sixth-order polynomial, and other prior methods.

Stage 1: In The Process Of Input Fuzzification, The Following Equations Are Utilized:

X_i (x)=[1/[1+(x-C_i)/a_i)^2]^(b_i) $_i$=1,2	**(1)**
Y_i (x)=[1/[1+((y-C_i)/a_i)^2]^(b_i) $_i$=1,2	**(2)**
R1=X1(x)×Y1(y)	***(3)***
R2=X1(x)×Y2(y)	***(4)***
R3=X2(x)×Y1(y)	***(5)***
R4=X2(x)×Y2(y)	***(6)***

Where X_i and Y_i are fuzzified input values, whereas a_i, bi and ci are the parameter sets from the Gaussian input membership function.

Stage 2: Application of fuzzy operators involves the use of the product (AND) to the fuzzified input. (3) to (6) represent the fuzzy relations obtained from the product of fuzzy operators [15].

Stage 3: In the application method of rules, the activation degree and normalization is implemented by using the following equations:

$G_i=R_i/RT \quad i=1,2,3,4 \quad (7)$

where

$RT=R1+R2+R3+R4 \quad (8)$

Stage 4: Aggregation of all outputs are obtained by using (9) which is the product of the normalized activation degree and individual output membership function,

$O_i=G_i(p_i x+g_i y+r_i) \quad i=1,2,3,4 \quad (9)$

Where pi, qi and ri are the parameters from the output membership function.

Stage 5: The required results are obtained through defecation

$OT=\sum Oi \quad i=1,2,3,4 \quad (10)$

These limitations can be overcome by the use of artificial intelligence techniques. The use of fuzzy logic in the design of a controller, either alone or in conjunction with a PI controller, is an example of this. Fuzzy logic control and artificial neural networks are both replaced by ANFIS. ANFIS combines the functionality of neural networks with fuzzy logic right to communicate knowledge. For solving real worked issues, ANFIS techniques have emerged from the meaning of Artificial Neural Networks (ANNs) and Fuzzy Inference Systems (FIS). An overview of artificial neural networks is depicted in Fig. 4.

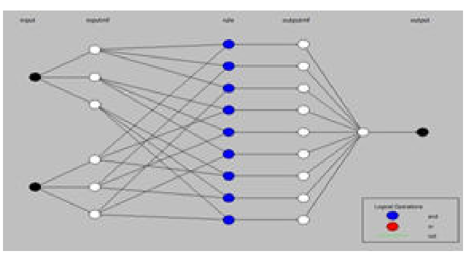

Fig. 3: Basic ANFIS structure.

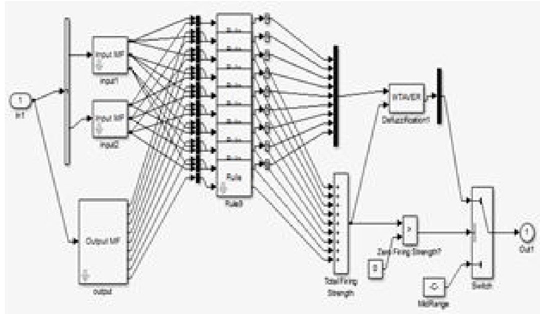

Fig. 4: Artificial Neural Network and Inference System

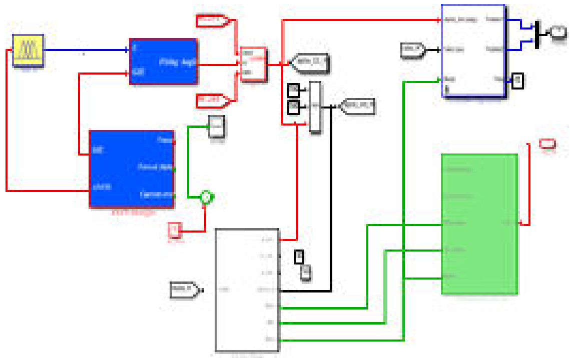

Fig. 5 shows HVDC System with ANFIS Controller.

The two universal bridge blocks connected in series provide the rectifier and inverter with a 12-pulse conversion. As shown in Fig. 6, the converter transformers (Wye grounded/Wye/Delta) are built with three-phase transformer blocks to build an 850 km long network. There are 12 thyristor converters are used in the HVDC transmission connection for implementation [16, 19].

This stage necessitates the use of two 6-pulse converters. Two 6-pulse converters in sequence are used to adjust the firing angle, one of which is a modified HVDC bridge. In order to create a 12-pulse converter, two 6-pulse Graetz bridges are linked together in series. The two 345 kV, 50 Hz, 6-pulse bridges are similar except for the fact that one has a slightly lower voltage. The AC supply voltages are 58.4° out of phase. The 60-degree phase shift cancels out some of the harmonic effects. Filters can be used to reduce harmonic distortion [17].

The firing angles are kept as low as possible so that voltage control may be accomplished. One method of controlling power is to control the current, while another method is to control the voltage. Maintaining a steady voltage in the DC link is essential to reducing power loss. The rectifier station is in charge of controlling the current, while the inverter is in charge of controlling the dc voltage [18]. Investigating how HVDC works and what it does and doesn't do was done by changing the angle of the rectifier station and the angle of the inverter station.

IV. COMPARISON ON PERFORMANCE OF INTELLIGENT CONTROLLERS BASED HVDC TRANSMISSION SYSTEM

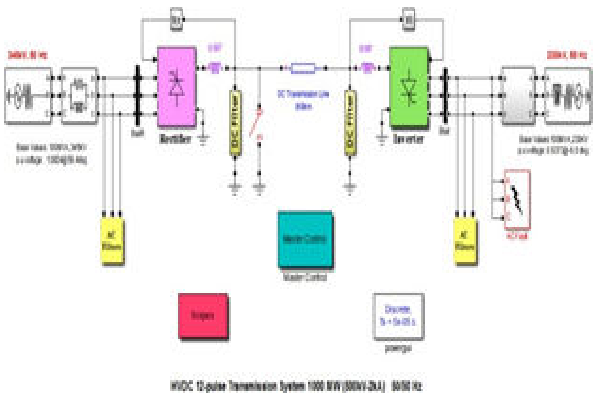

Fig. 6: Simulink diagram of the HVDC Circuit.

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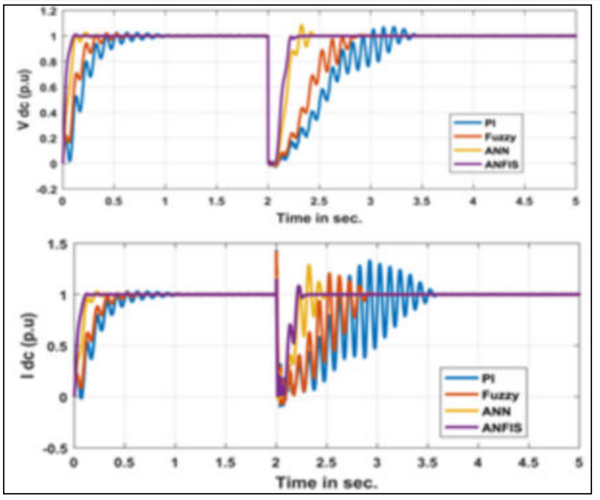

Fig. 7: Voltage And Current Response Of PI And Intelligent Controllers To Dc Side On Rectifier End

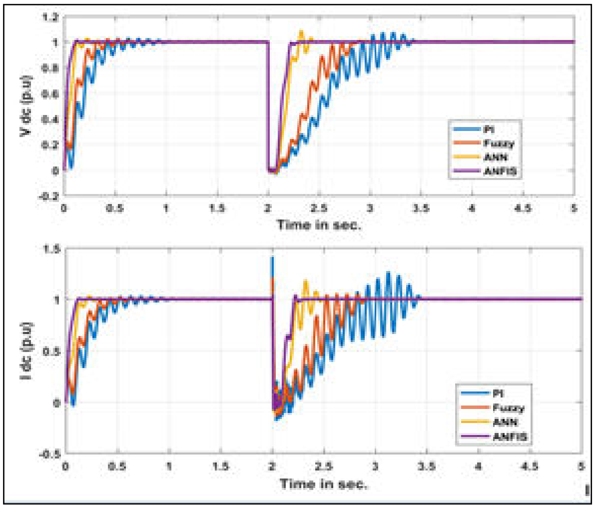

Fig. 8: Voltage And Current Response Of PI And Intelligent Controllers To Dc Side Of Inverter End

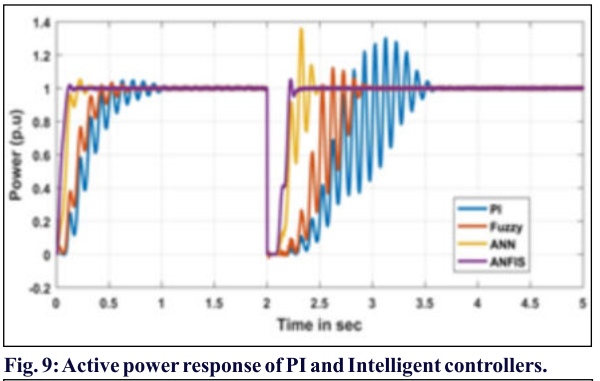

Fig. 9: Active power response of PI and Intelligent controllers.

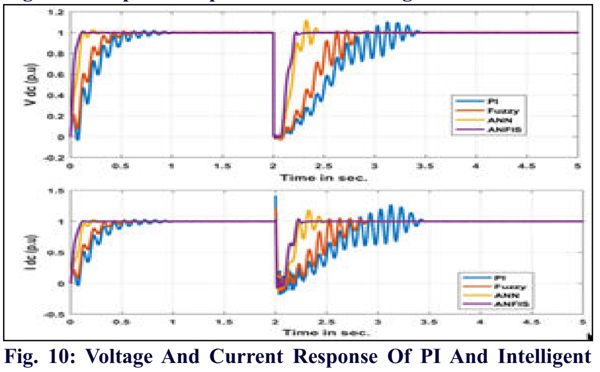

Fig. 10: Voltage And Current Response Of PI And Intelligent Controllers To Line-To-Ground Fault At Rectifier End

Fig. 9 shows the change process of the active power of the HVDC system with dc fault with the PI controller and the fuzzy logic, artificial neural network and Inference system (ANFIS). It is clear that, for dc fault, both the controllers perform well, but ANFIS gives better transient performance and quite a low overshoot as compared to the other controllers.

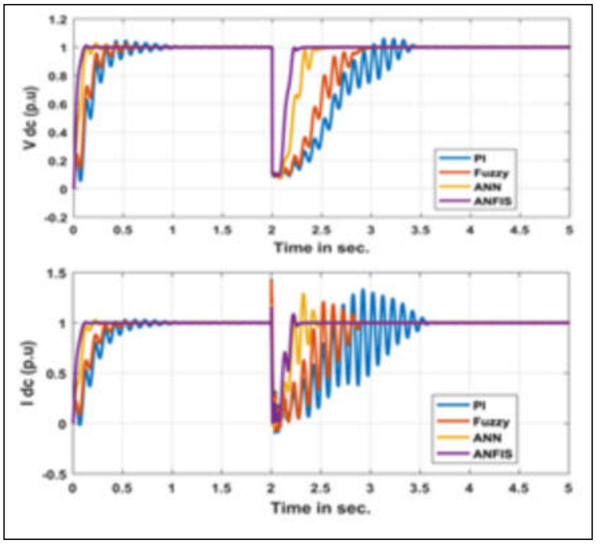

Fig.11: Voltage And Current Response Of PI And Intelligent Controllers To Line-to-ground Fault At Inverter End

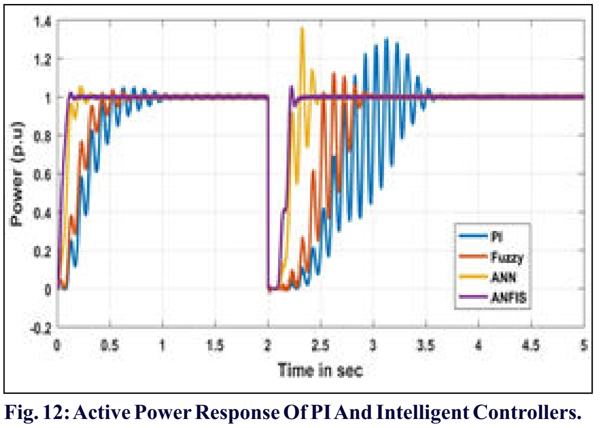

Fig. 12: Active Power Response Of PI And Intelligent Controllers.

In Fig. 10 and Fig. 11, it is observed that a line-to-ground fault occurs at 2.0 sec. For duration of 0.05 sec., the fault is created on phase A of the rectifier and inverter sides of the HVDC system. The artificial neural network and inference system (ANFIS) activate and clear the fault and performs better than the fixed-gain PI controller. The rectifier side dc current suffers from prolonged oscillations and, consequently, more commutation failures occur in the case of a fixed-gain PI controller. The fixed- gain PI controller takes longer time to recover after a fault is cleared due to the narrow range of optimum controller gain parameters. Once the fault is cleared, at t = 2.05 sec, the system comes back to its normal operation.

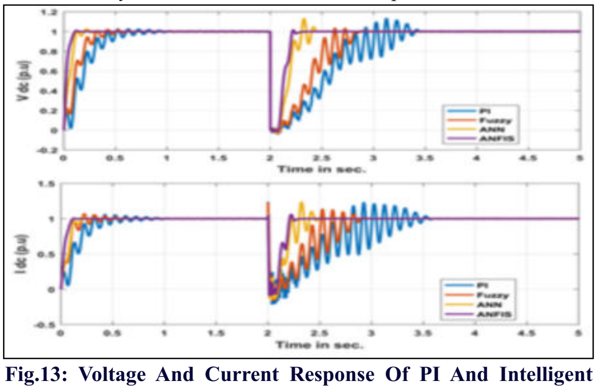

Fig.13: Voltage And Current Response Of PI And Intelligent

Controllers To Two Phase To Ground Fault At Rectifier End

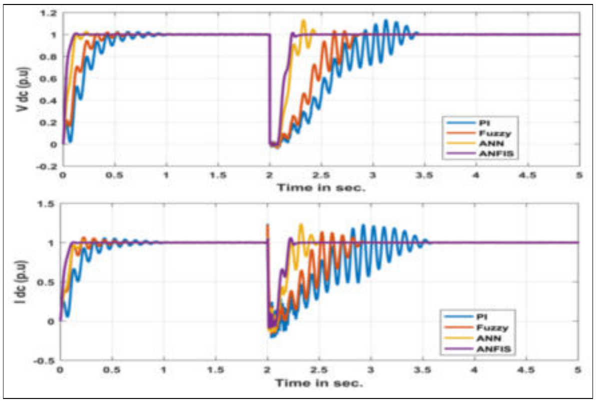

Fig.14: Voltage And Current Response Of PI And Intelligent Controllers To Two Phase To Ground Fault At Inverter End

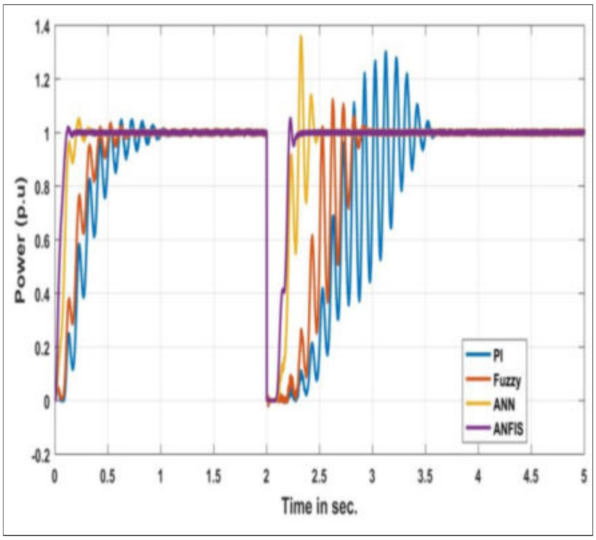

Fig. 15: Active Power Response Of PI And Intelligent Controllers.

In Fig. 13 and Fig. 14, it is observed that a two-phase fault occurs at time 2.0 sec. the fault is created for duration of 2.05 sec. on phase A and phase B of the rectifier and inverter sides of HVDC System. Artificial neural network and inference system (ANFIS) activate and clear the fault. The ANFIS performs better than the fixed-gain PI controller. The rectifier side DC current suffers from prolonged oscillations and consequently more commutation failures occur in the case of fixed-gain PI controller. The fixed-gain PI controller takes longer time to recover after fault is cleared due to the narrow range of optimum controller gain parameters. ANFIS reduces the recovery time by 1.2 sec after the disturbance. Once the fault is cleared, at t=2.05 sec the system comes back to its normal operation.

In Fig. 16 and Fig. 17, it is observed that a three-phase fault occurs at time 2.0 sec. the fault is created for a duration of 0.05 sec. on phase A, B and phase C of the rectifier and Inverter sides of HVDC System. Artificial Neural Network and Inference System (ANFIS) activate and clear the fault. The ANFIS performs better than the fixed- gain PI controller. The rectifier side dc current suffers from prolonged oscillations and consequently more commutation failures occur in the case of fixed-gain PI controller. The fixed-gain PI controller takes longer time to recover after fault is cleared due to the narrow range of optimum controller gain parameters. ANFIS reduces the recovery time by 1.2 sec after the disturbance. Once the fault is cleared, at t=2.05 sec the system comes back to its normal operation.

Figs.9, 12,15 and 18 show the change process of the active power of HVDC system after dc, a line-to-ground fault, two-phase fault and three-phase fault are occurred with PI controller and the knowledge based controllers. It is clear that for dc fault, line-to-ground fault, two-phase fault and three-phase fault, both the controllers perform well but ANFIS gives a better transient performance and quite a low overshoot as compared to the other controllers.

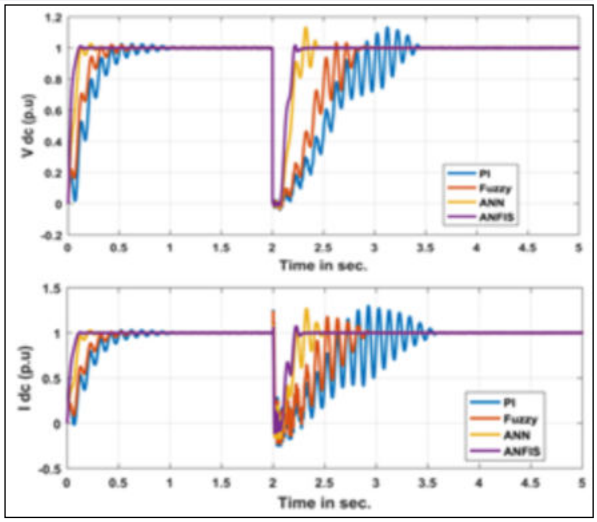

Fig.16: Voltage And Current Response Of PI And Intelligent Controllers To Three Phase To Ground Fault At Rectifier End

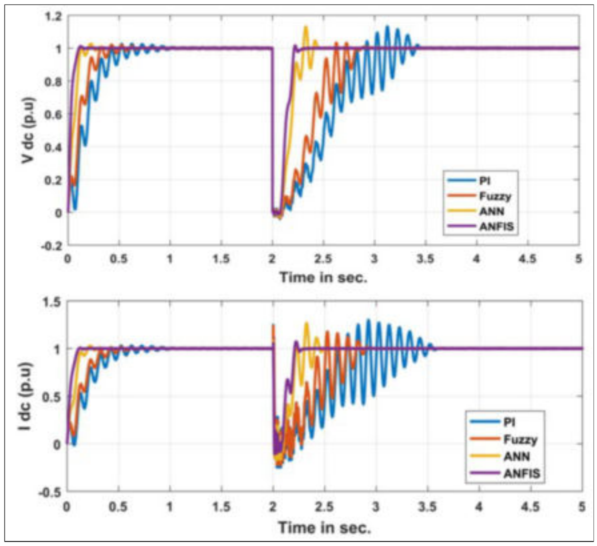

Fig.17: Voltage And Current Response Of PI And Intelligent Controllers To Three Phase To Ground Fault At Inverter End

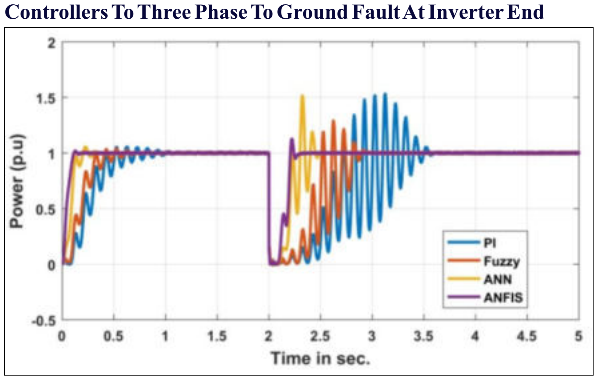

Fig. 18: Active Power When Three Phase Fault Occurs.

CONCLUSION

An ANFIS controller for an HVDC System is proposed in this work, which combines fuzzy logic and neural networks. The feed forward neural network architecture is used in the controller. The simulation results clearly reveal that the adaptive neuro-fuzzy controller (ANFIS) was successfully implemented in the MATLAB/SIMULINK. The results show that an adaptive neuro-fuzzy controller (ANFIS) efficiently updates the rule base with changing system conditions and employs a feed forward neural network design that performs a conventional PI controller. An HVDC system ANFIS controller is compared to knowledge based controllers presented in this work. Because of this, ANFIS is a more intelligent way to control HVDC

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system than the other knowledge based and conventional controllers.

APPENDIX A

Following are the parameters of the HVDC system chosen for the simulation studies:

Parameters	Rectifier	Inverter
AC voltage base	345kV	230kV
Base MVA	100MVA	100MVA
Transf. tap (HV side)	1.01pu	0.989pu
Voltage source	$1.088\angle 22.18^{o}$	$0.935\angle -23.14^{o}$
Nominal DC voltage	500kV	500kV
Nominal DC current	2kA	2kA

CIGRE HVDC Benchmark System Data

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