



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

IJIRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 10, Issue 10, October 2021

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 7.569



Modern Control Technique to Enhance Power Flow and Stability of Conventional HVDC System

Chinthalapati Vasavi¹, Dr.K.Rama Sudha²

P.G. Student, Department of EEE, Andhra University College of Engineering, Visakhapatnam, India¹

Professor, Department of EEE, Andhra University College of Engineering, Visakhapatnam, India²

ABSTRACT: With day-by-day growth in population, industrialization and technology the demand for electricity is increasing enormously. Electricity is important part of modern life and it helps us in many ways. Electric power transmission is one of the crucial part in power system network. Long distance AC transmission is subject to certain problems which can be resolved with DC transmission. In transmission of bulk power, HVDC transmission has played a major role from a very long time. HVDC Transmission has advantage of asynchronous operation and reduced losses. This paper presents a simulation of CIGRE HVDC Benchmark system to transfer bulk amount of power between two converter stations. To maintain constant power flow, power flow control is employed. The power flow control is done by controlling the rectifier and inverter stations. In this paper to control power flow, Conventional controller of HVDC station is replaced with Artificial neural network controller. This is performed by using the error signal obtained from conventional controller and it is used to feed as input to ANN controller which produces alpha order signal to generate firing pulses to the converter stations. Improvement in power flow during normal operating conditions and stability during fault conditions is observed with Artificial neural network controller compared to conventional controller.

KEYWORDS: CIGRE HVDC Benchmark System, converter stations, rectifier control, inverter control, error signal, alpha order, Power flow, fault, Stability, Conventional controller, Artificial neural network controller

I. INTRODUCTION

High and growing electricity demands need the transmission of electrical power over long distances. Right-of-way (ROW) and better efficiency are some of the challenges that have faced the power transmission industry over the years. High Voltage Direct Current (HVDC) technology is mainly used in long distances and it is gaining popularity over AC technology in this context. The modern form of HVDC employs the technology that was developed and commercialized some 50 years ago by ABB company. DC power transmission at low voltages has high losses over long distances, thus giving rise to High Voltage Alternating Current (HVAC) electrical systems. However HVAC transmission for long distances have many disadvantages like synchronous operation condition, high charging currents, skin and ferranti effect etc. These can be overcome with HVDC. With improvement in power electronic technologies these systems are highly improved. Fast and flexible control helps to maintain stability.

II. CIGRE HVDC SYSTEM MODEL

Considered system is a monopolar 500kV, 1000 MW HVDC link with 12-pulse converters on both rectifier and inverter side, connected to a weak AC system that provides a considerable degree of difficulty for DC controls [1]. Reactive power compensation and filters are provided on both sides. The power circuit of the converter consists of the following sub-circuits.

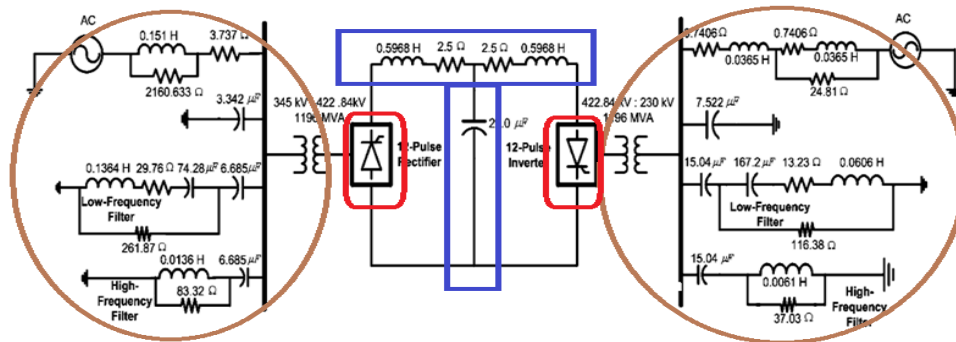


Fig 2.1 Single Line Diagram of CIGRE benchmark HVDC System

a) Three Phase Source

A three-phase AC voltage source in series with an R-L combination is used to model the source.

b) AC Side

The AC sides of the HVDC system consist of supply network, filters, and transformers on both sides of the converter. The AC supply network is represented by a Thevenin equivalent voltage source with equivalent source impedance. AC filters are added to absorb the harmonics generated by the converter as well as to supply reactive power to the converter.

c) DC Side

The DC side of the converter consists of smoothing reactors for both rectifier and the inverter side. The DC transmission line is represented by an equivalent T network, which can be tuned to fundamental frequency to provide a difficult resonant condition for the modelled system.

d) Converter

The converter stations are represented by 12-pulse configuration with two six-pulse valves in series. In the actual converter, each valve is constructed with many thyristors in series. Each valve has a (di/dt) limiting inductor, and each thyristor has parallel RC snubbers.

e) Power Circuit Modelling

The rectifier and the inverter are 12-pulse converters constructed by two universal bridge blocks connected in series. The converter transformers are modelled by one three-phase two winding transformer with grounded Wye-Wye connection, the other by three-phase two winding transformer with grounded Wye-Delta connection. The converters are interconnected through a T-network.

f) Universal Bridge Block

The universal bridge block implements a universal three-phase power converter that consists of six power switches connected as a bridge. The type of power switch and converter configuration can be selected from the dialog box. Series RC snubber circuits are connected in parallel with each switch device. The vector gating signals are six-pulse trains corresponding to the natural order of commutation. The measurements are not realized in this model.

III. HVDC CONTROL CHARACTERISTICS

In general control is applied to both the terminals. Under steady state, typically rectifier would be act as constant current source i.e. constant current control and inverter will operate as constant counter voltage source i.e. constant extinction angle. The current order at the rectifier is determined by the manipulation of power order and inverter DC voltage. To maintain stability at rectifier, it is necessary to have less ($I_{dref} - I_d$) deviation in DC current and also ($\gamma_{meas} - \gamma_{ref}$) deviations should be keep as low as possible for inverter stability. The intersection of two modes gives normal operation point.

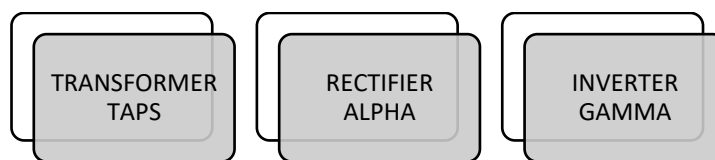
3.1 Control Variables for Constant Power Flow Control

The control model mainly consists of (α/γ) measurements and generation of firing signals for both the rectifier and inverter. The current equation for the control is as follows[6]

$$I_d = (E_{dr} \cos \alpha_r - E_{di} \cos \gamma_i) / (R_{cr} + R_{di} - R_{ci})$$

$$E_{dr} = (A_r * E_r / T_r) \cos \alpha_r$$

$$E_{di} = (A_i * E_i / T_i) \cos \gamma_i$$



Following are the controllers used in the control schemes:

1. Extinction Angle (γ) Controller
2. Current Controller;
3. Voltage Dependent Current Limiter (VDCOL).

3.2 Rectifier Control

The rectifier control system uses Constant Current Control (CCC) technique. The reference for current limit is obtained from the inverter side. This is done to ensure the protection of the converter in situations when inverter side does not have sufficient DC voltage support or does not have sufficient load requirement. The reference current used in rectifier control depends on the DC voltage available at the inverter side. DC current on the rectifier side is measured using proper transducers and passed through necessary filters before they are compared to produce the error signal. The error signal is then passed through a PI controller, which produces the necessary firing angle order. The firing circuit uses this information to generate the equidistant pulses for the valves using the technique.

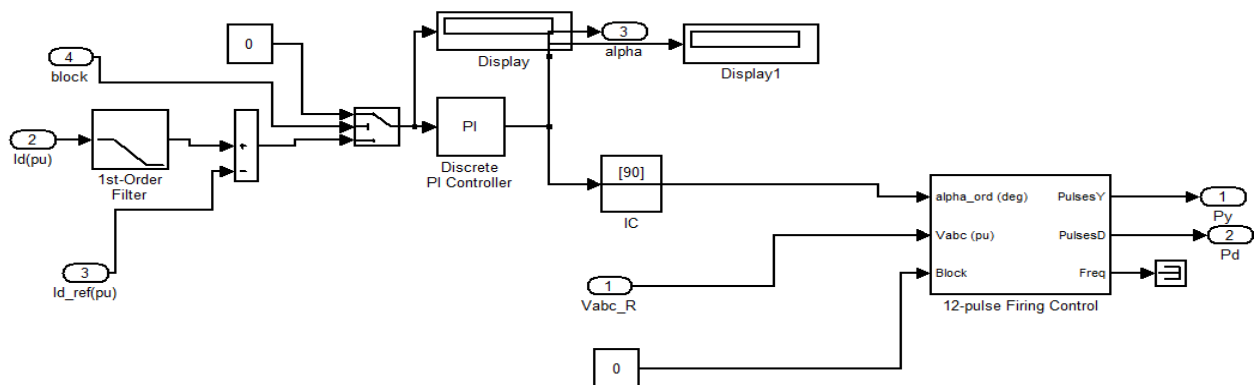


Fig 3.1. Rectifier control with PI

3.3 Inverter Control

The Extinction Angle Control or γ control and current control have been implemented on the inverter side. The CCC with Voltage Dependent Current Order Limiter (VDCOL) has been used here through PI controllers. The reference limit for the current control is obtained through a comparison of the external reference (selected by the operator or load requirement) and VDCOL (implemented through lookup table) output. The measured current is then subtracted from the reference limit to produce an error signal that is sent to the PI controller to produce the required angle order. The γ control uses another PI controller to produce gamma angle order for the inverter. The two angle orders are compared, and the minimum of the two is used to calculate the firing instant[5].

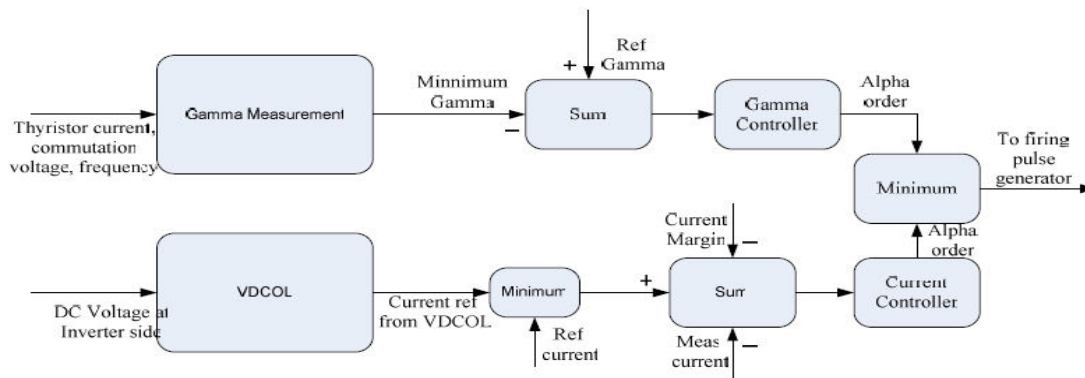


Fig 3.3. Inverter control with gamma measurement technique

The current extinction time is determined from the current threshold. The six gamma angles are determined using six thyristor currents and the six commutation voltages are derived from the three-phase-to-ground AC voltages measured at the 12 primary of the converter transformer. The minimum gamma value is considered for the control action. For a 12-pulse converter, two gamma measurement units are used, and the smaller of the two gamma outputs is compared with the reference gamma to produce the error signal. The firing angle orders from the CCC and from the gamma controller (CEA) are compared and the minimum is used to produce firing pulses for the valve.

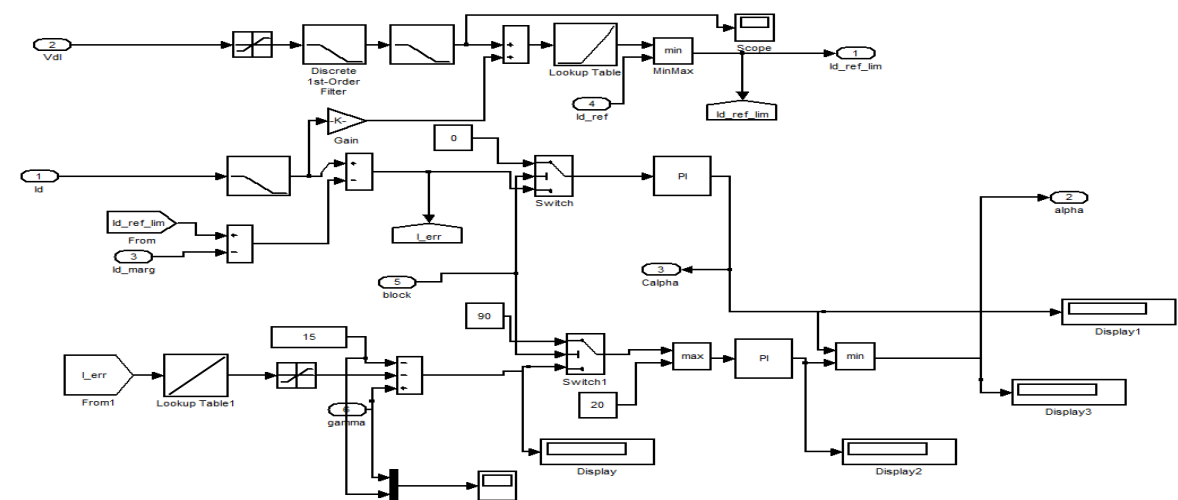


Fig 3.4. Inverter control with PI.

IV. ARTIFICIAL NEURAL NETWORKS

4.1 Artificial Neurons

Artificial Neural Networks are based on the neural structure of the brain. The brain basically learns from experiences. It is natural proof that are beyond the scope of current computers are indeed solvable by small energy efficient packages. This brain modelling also promises a less technical way to develop machine solutions.

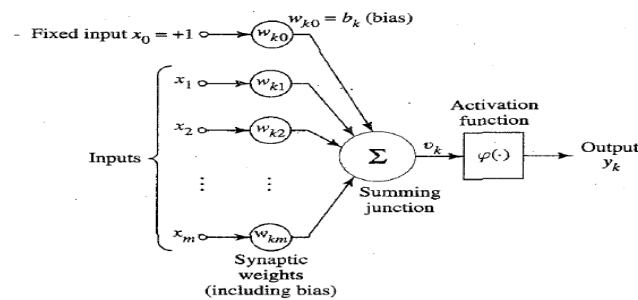


Figure 4.1. Artificial Neural Networks

4.2 Training an Artificial Neural Network

Once a network has been structured for a particular application, that network is ready to be trained. To start this process, the initial weights are chosen randomly. Then, the training, or learning, begins. There are two approaches to training – ‘SUPERVISED’ and ‘UNSUPERVISED’. Supervised training involves a mechanism of providing the network with the desired output either by manually “grading” the network’s performance or by providing the desired outputs with the inputs. Unsupervised training is where the network has to make sense of the inputs without outside help. The vast bulk of networks utilize supervised training[4].

Typical diagrams for supervised training of a network is given in figure 4.2.

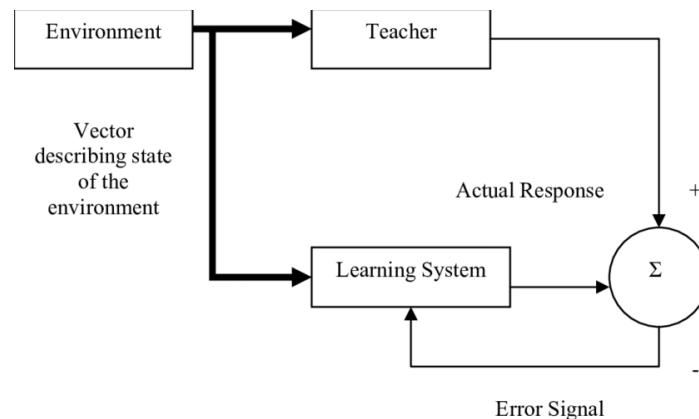


Figure 4.2. Supervised training

There are two types of training procedures according to the way in which the inputs are applied to the network. They are ‘incremental training’ where each training pair will be applied one after the other and ‘batch training’ in which entire set of training pairs will be applied at once[8]. The syntaxes for them are as below:

SYNTAX:

Batch Training : net = train (net, p, t);

Incremental Training : [net, a, e] = adapt (net, p, t)

4.3. Training Parameters

SYNTAX	DESCRIPTION
net.trainparam.epochs	indicates maximum number of epochs for training
net.trainparam.lr	specifies the learning rate
net.trainparam.goal	specifies the performance goal
net.trainparam.show	specifies number of epochs between Showing progress

V. SIMULATION MODEL AND RESULTS

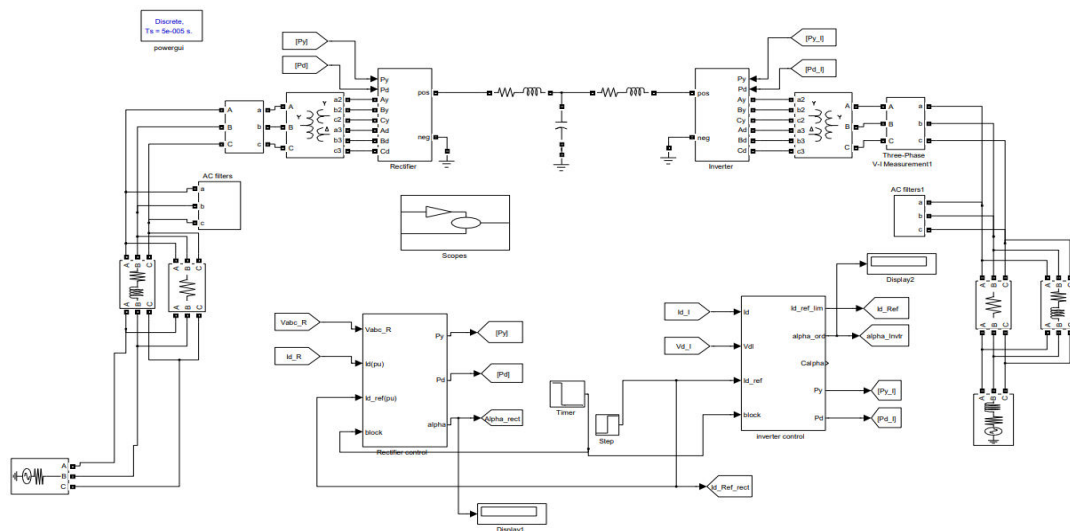


Fig 5.1. Simulink model of CIGRE Benchmark HVDC System

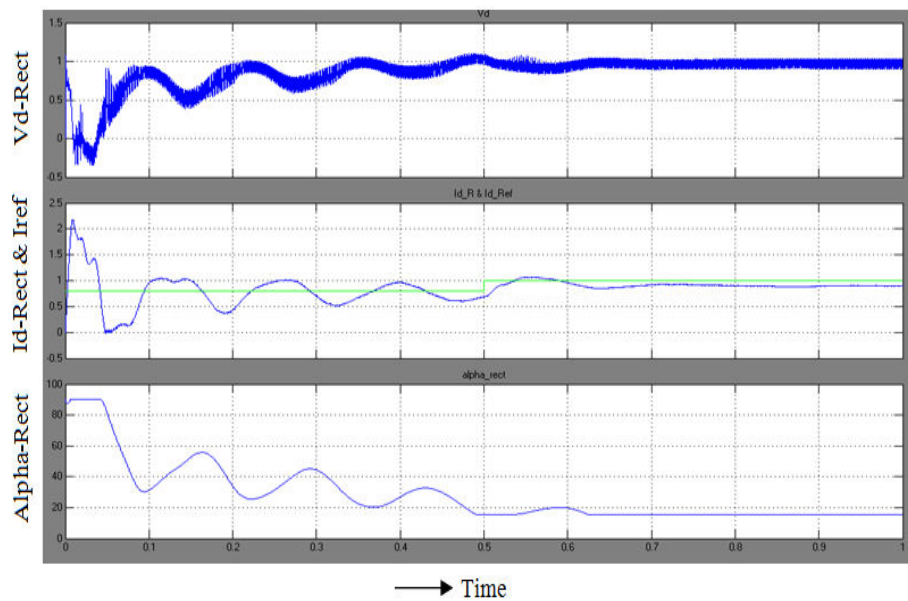


Fig (a). Rectifier side DC Voltage, DC Current and firing angle order with PI

From the above graph I_{d_R} and I_{d_Ref} are compared to produce an error signal which gives the firing angle order ($\alpha=15.6$ deg).

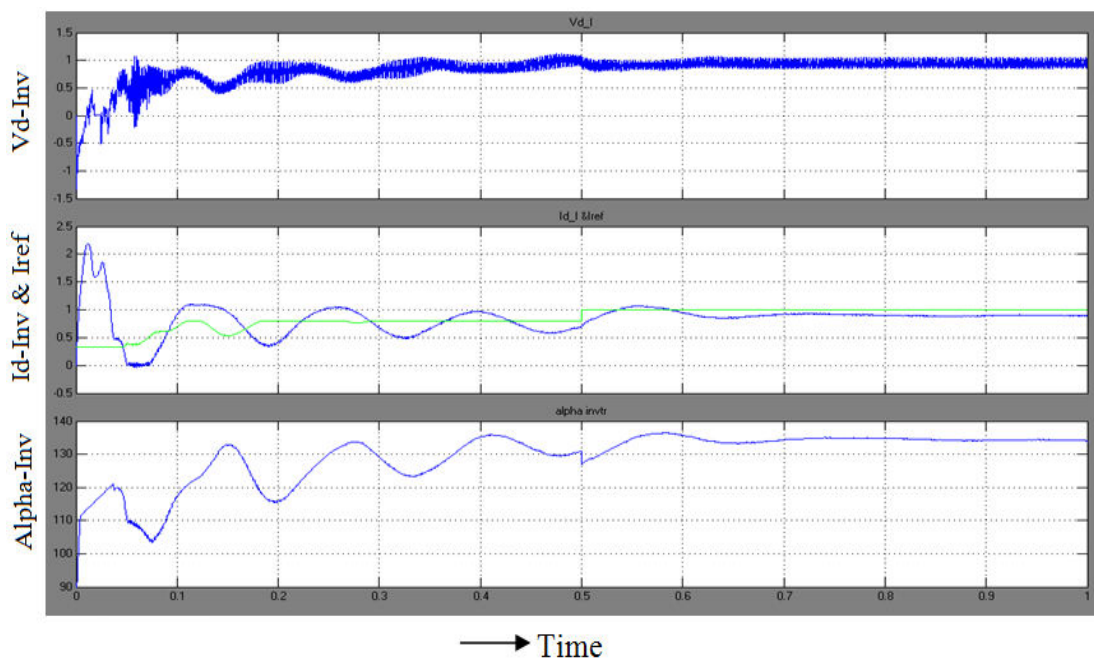
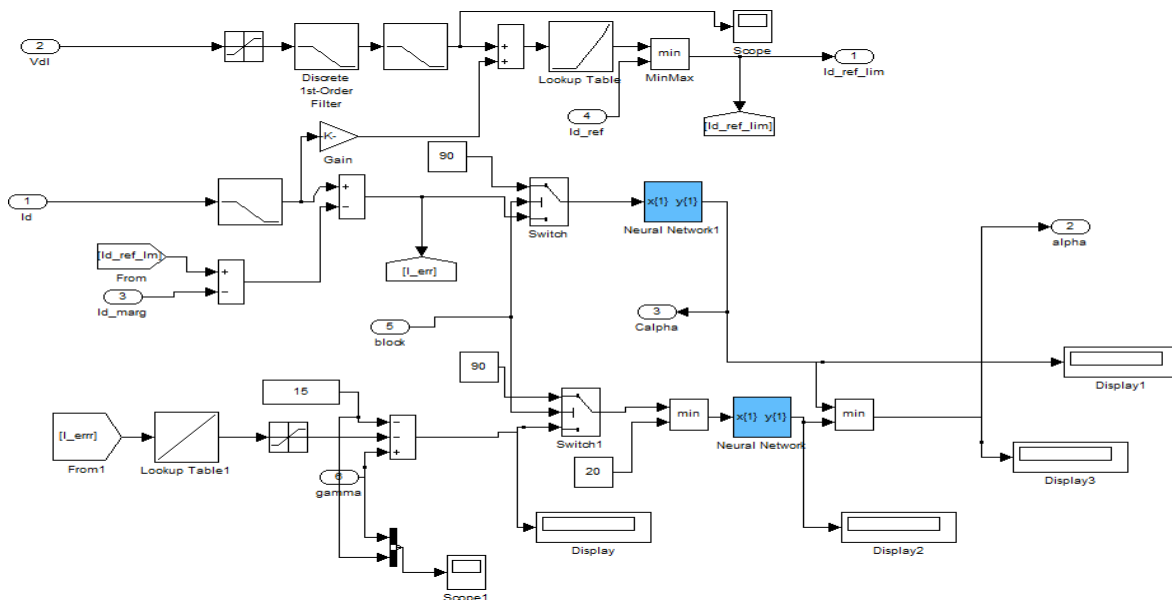


Fig (b). Inverter side DC Voltage, DC Current and firing angle order with PI

From the above graph I_{d_I} and I_{d_Ref} are compared to produce an error signal which gives the firing angle order ($\alpha_{inv}=134$ deg).

For inverter constant current control and constant extinction angle control is employed and minimum of them is considered as firing angle order as shown in fig.5.3



IJRSET © 2021

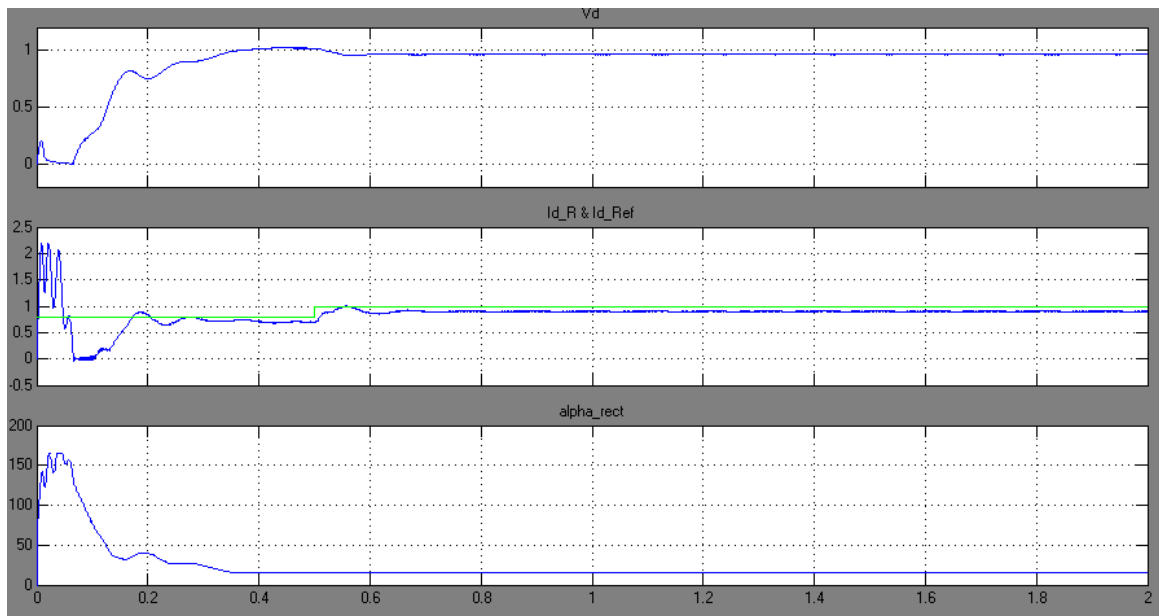


Fig (c). Rectifier side DC Voltage, DC Current and firing angle order with NN

From the above graph I_{d_R} and $I_{d_{Ref}}$ are compared to produce an error signal which gives the firing angle order ($\alpha=15.6$ deg).

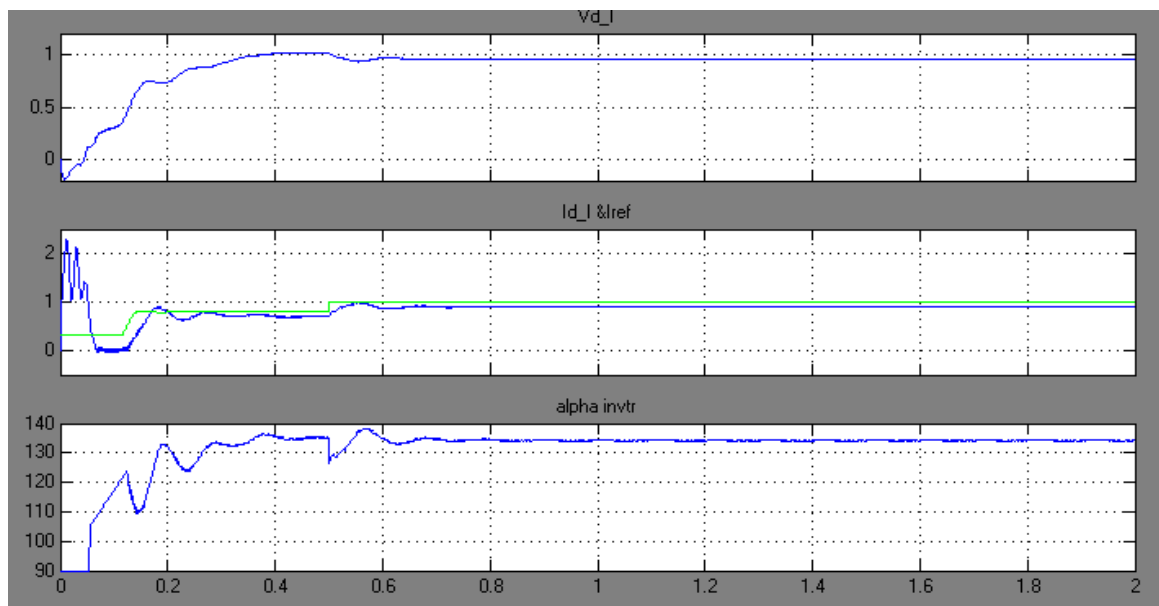


Fig (d). Inverter side DC Voltage, DC Current and firing angle order with nn

Table 5.1. Comparison between PI and ANN for Rectifier Firing Angle $\alpha=15.50$

Controller	Rectifier α (degrees)	Inverter α (degrees)	I_{d_R} (p.u)	I_{d_I} (p.u)	V_{d_R} (p.u)	V_{d_I} (p.u)
With PI	15.5	134	0.8954	0.8913	1.016	0.8582
With ANN	15.5	142	0.903	0.9024	0.96	0.95

From the above table, the DC currents and voltages of both rectifier and inverter with ANN shows better results when compared with PI controller.

Table 5.2. Effect Due to Change in Rectifier Firing Angle with pi

Rectifier α (degrees)	Inverter α (degrees)	I_{d_R} (p.u)	I_{d_I} (p.u)	V_{d_R} (p.u)	V_{d_I} (p.u)
15.5	134	0.8954	0.8913	1.016	0.8582
30	128.6	0.8496	0.844	0.83	0.840
45	119.4	0.6294	0.6261	0.749	0.6825
60	109.9	0.3848	0.3989	0.358	0.35
75	98.62	0.2469	0.2394	0.28	0.26

Table 5.3. Effect Due to Change in Rectifier Firing Angle with ANN

Rectifier α (degrees)	Inverter α (degrees)	I_{d_R} (p.u)	I_{d_I} (p.u)	V_{d_R} (p.u)	V_{d_I} (p.u)
15.5	142	0.903	0.9024	0.96	0.95
30	130	0.852	0.848	0.835	0.847
45	120.5	0.753	0.734	0.784	0.702
60	112	0.452	0.432	0.468	0.452
75	101	0.301	0.312	0.321	0.312

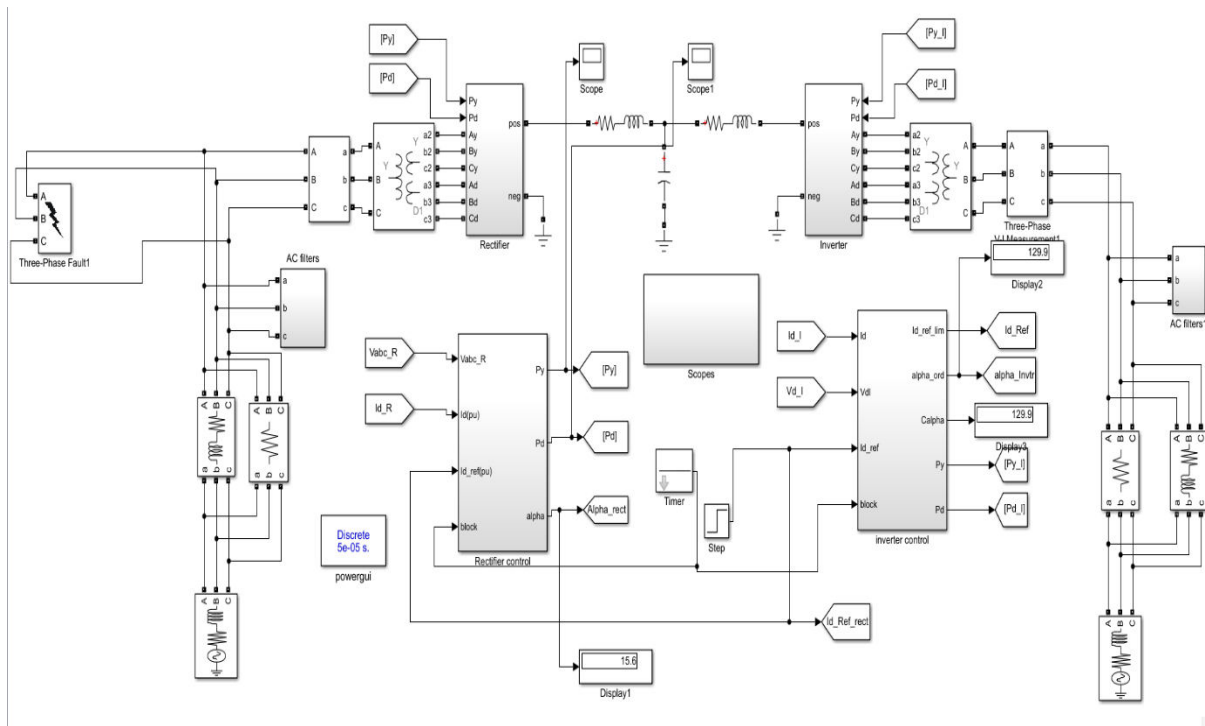


Fig 5.4. Fault applied at both rectifier and inverter side

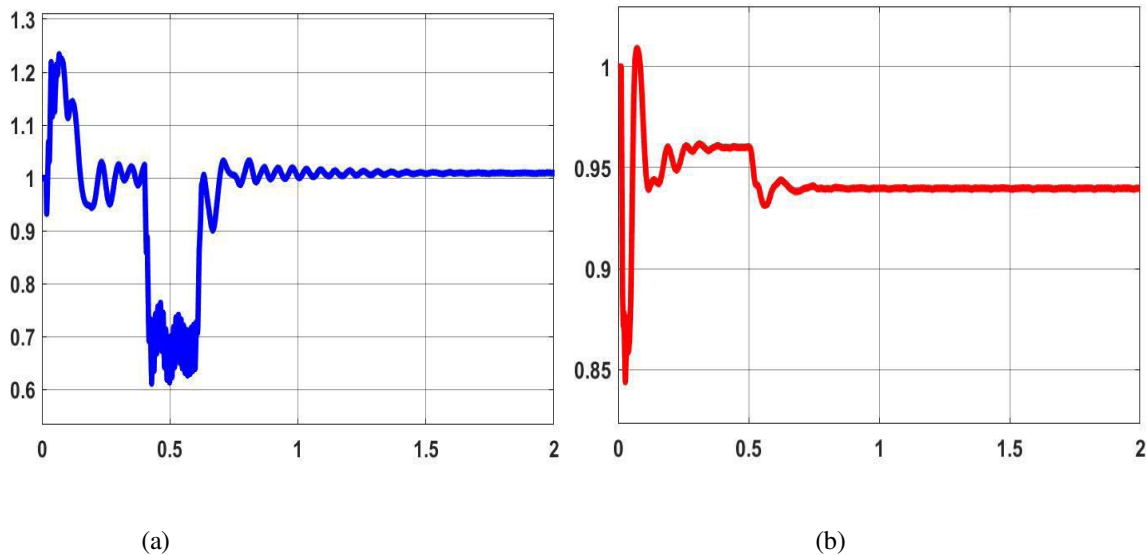


Fig.(e) Voltage response with LG fault at rectifier side with a)PI controller b)ANN controller

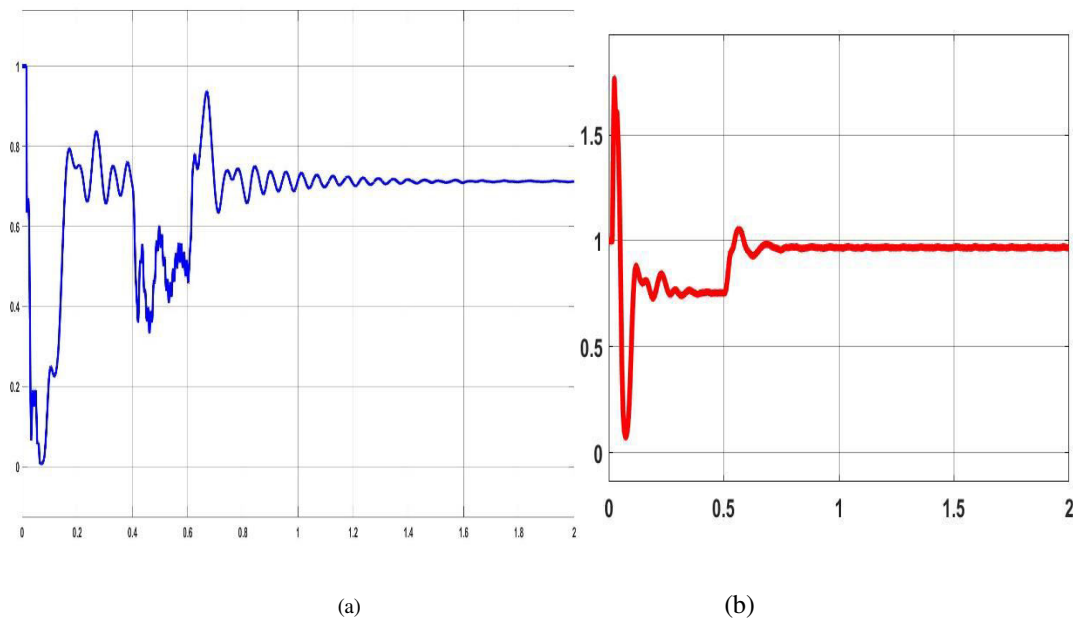


Fig.(f). current response with LG fault at rectifier side with a)PI controller b)ANN controller

By observing fig(e) and fig (f) we can conclude that when LG fault is applied between 0.4 to 0.6 ,the system with ANN controller recovered very quick when compared with PI controller.

Table 5.4. Effect due to LLLG Fault at Rectifier Side with PI and ANN

Controller	FIRING ANGLE	Vdc_R	Vdc_I	Idc_R	Idc_I	Pdc_R	Pdc_I
PI	15.5	0.7873	0.8579	0.6456	0.6606	0.5082	0.5667
ANN	15.5	0.9634	0.9563	0.9015	0.8991	0.8685	0.8598

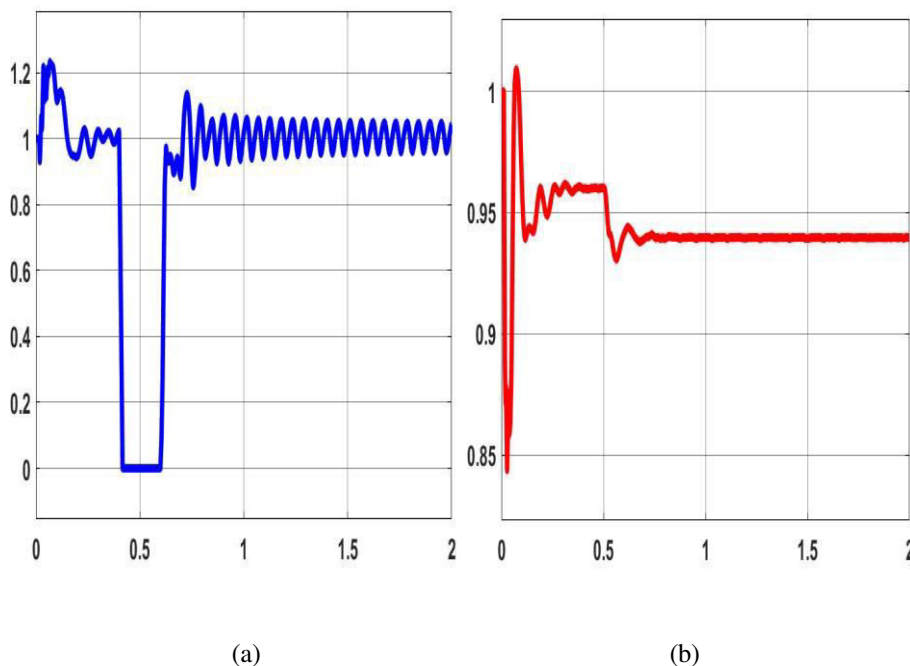
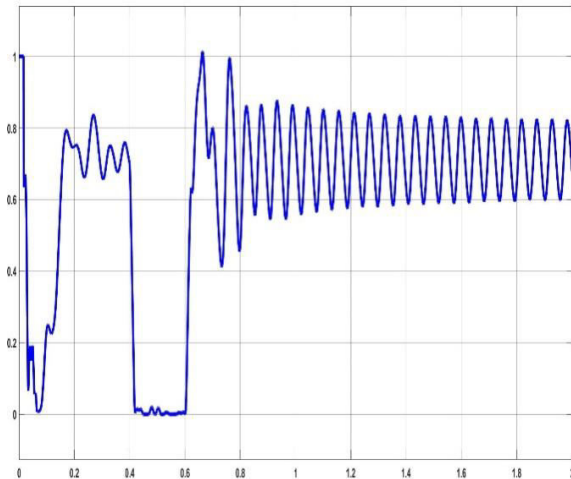


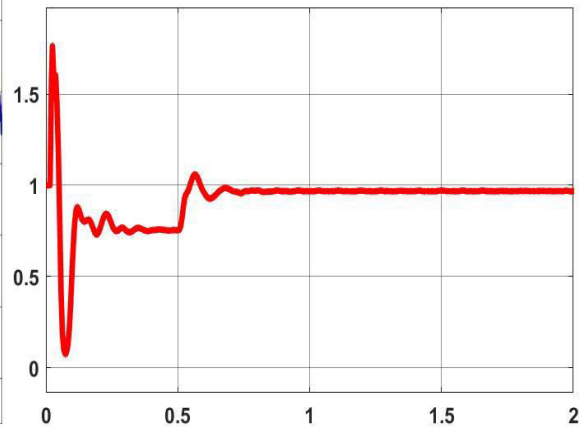
Fig (g) Rectifier voltage response with a)PI controller and b) ANN Controller

Table 5.7. Voltage response parameters in rectifier side

Parameter	PI Controller	ANN Controller
Peak value	1.21	1.01
Peak overshoot	24.7	7.503
Rise time	1.905	0.92
Settling time	2	0.65



(a)

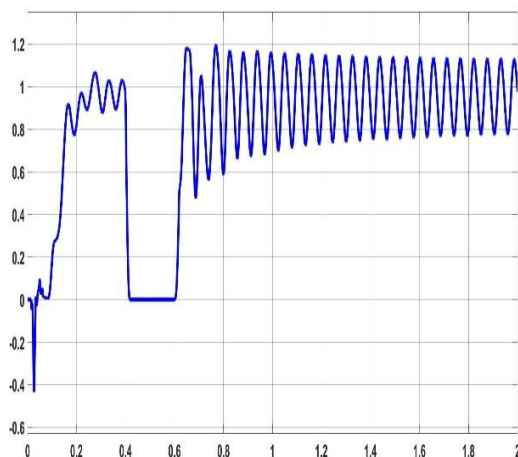


(b)

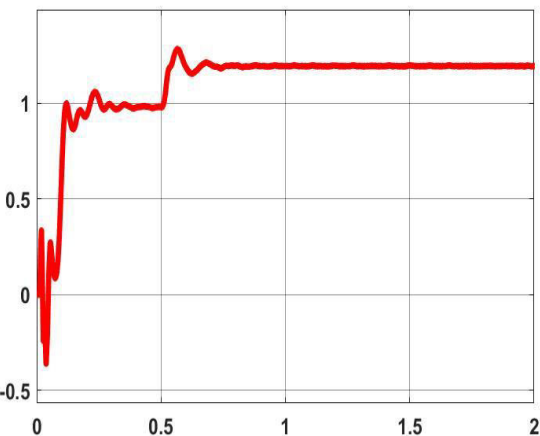
Fig(h)Current response of rectifier with a) PI controller and b)ANN Controller

Table 5.7. Current response parameters in rectifier side

Parameter	PI Controller	ANN Controller
Peak value	1.0905	1.0905
Peak Overshoot	48.51	12.22
Rise time	2	0.8
Settling time	0.4	0.65



(a)



(b)

Fig(i) Real Power Response with a)PI Controller and b)ANN Controller

Table 5.8. Real power response parameters in rectifier side

Parameter	PI controller	ANN controller
Peak value	1.195	1.2
Peak Overshoot	30.46	8.006
Rise time	0.5	0.4
Settling time	2	0.8

VI. CONCLUSION AND FUTURE SCOPE

6.1. Conclusions

In this project, a monopolar 500KVHVDC system is designed to control the power flow between two converter stations with conventional controller and Artificial Neural Networks. For rectifier side current control is used and for inverter side both current and extinction angle control is implemented. In order to transfer maximum power in the DC link, we have to maintain minimum alpha. The error signal is passed through a PI and Artificial Neural Networks controller, which produces the necessary firing angle order. The firing circuit uses this information to generate the equidistant pulses for the valves in the converter station. Later LG and LLLG fault is applied to the system and response is observed for PI and ANN Controllers.

During steady state conditions, the power flow improvement with ANN controller is appreciable when compared with PI controller. During fault conditions the recovery of the system post fault is drastically improved with help of ANN controller. By observing the response parameters of the response one can clearly conclude ANN controller has fast control action compared with PI. This in turn increases power system HVDC transmission stability.

6.2 Future Scope

The scope for further work is to control the power flow in the HVDC link using Fuzzy controller and ANFIS (adaptive neuro fuzzy inference system) can be used.

VII. ACKNOWLEDGMENT

If words are considered as symbol of approval and tokens as knowledge, then let the words play the heralding role of expressing my gratitude.

I would like to express my deepest gratitude to my guide, Dr. K. Ramasudha, Professor, Department of Electrical Engineering, Andhra University College of Engineering (A), Visakhapatnam for her guidance. I shall always cherish our association for her encouragement, approachability and freedom of thought and actions which I had enjoyed during thesis work.

I would like to thank all my friends, faculty members lab staff and everyone who helped indirectly for their good wishes and constructive support in building up the work. At this point I have to express my indebtedness to my beloved parents, for their blessings and encouragement in completing my work fruitfully.

REFERENCES

- [1] M. O. Faruque, Yuyan Zhang and V. Dinavahi, "Detailed modeling of CIGRE HVDC benchmark system using PSCAD/EMTDC and PSB/SIMULINK," IEEE Trans. Power Delivery, vol.21, no.1, pp. 378 –387, Jan. 2006.
- [2] Das, B.P.; Watson, N.; Yonghe Liu; , "Simulation study of conventional and hybrid HVDC rectifier based on CIGRÉ benchmark model using PLL-less synchronisation scheme," Power Engineering and Optimization Conference (PEOCO), 2011 5th International , vol., no., pp.312-317, 6-7 June 2011doi: 10.1109/PEOCO.2011.5970433.
- [3] Ashfaq Thahir, M.; Kirthiga, M.V.; "Investigations on modern self-defined controller for hybrid HVDC systems," TENCON 2011 - 2011 IEEE Region 10 Conference, vol., no., pp.938-943, 21-24 Nov. 2011doi: 10.1109/TENCON.2011.6129248.
- [4] Das, B.P.; Watson, N.; Yonghe Liu; , "Comparative study between gate firing units for CIGRE benchmark HVDC rectifier," Industrial Electronics and Applications (ICIEA), 2011 6th IEEE Conference on , vol.,no.,pp.299-306,21-23June2011 doi: 10.1109/ICIEA.2011.5975598.



- [5] Sood, V.K.; Khatri, V.; Jin, H.; , "EMTP modelling of CIGRE benchmark based HVDC transmission system operating with weak AC systems," Power Electronics, Drives and Energy Systems for Industrial Growth, 1996., Proceedings of the 1996 International Conference on , vol.1, no., pp.426-432 vol.1, 8-11 Jan 1996doi: 10.1109/PEDES.1996.539653.
- [6] HVDC Transmission course from nptel.
- [7] Kala Meah, A.H.M. Sadrul Ula, "Simulation Study of the Frontier Line as a Multi-Terminal HVDC System," IEEE PES General Meeting, July 20- 24, 2008, Pittsburg, PA, USA.
- [8] W.Miller,R.SuttonandP.Werbos,"NeuralNetworksforControl",Cambridge,MA:MIT Press, 1991
- [9] E. W. Kimbark, "Direct Current Transmission," Vol. I, Wiley-Inter-Science, New York, 1971.
- [10]K. R. Padiyar, "HVDC Power Transmission Systems: Technology and System Interactions," New Age Internationals (P) Limited Publishers, New Delhi, 1996.



**Impact Factor:
7.569**



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

 **9940 572 462**  **6381 907 438**  **ijirset@gmail.com**



www.ijirset.com

Scan to save the contact details