ISSN (Online): 2456-5717
International Journal of Advanced Research in Basic Engineering Sciences and Technology (IJARBEST)
Vol.4 Issue.2 February 2018

Voltage Ripple Reduction for HVDC System Using Fuzzy Logic Controller

Sappa Venkata Taraka Ranjit Kumar[1], Dr. A Nagamalleswara Rao[2]

PG Scholar, Department of Electrical and Electronics Engineering, Swamy Vivekananda Engineering College, Kalavarai, Vizianagaram, India[1]
Professor, Department of Electrical and Electronics Engineering, Swamy Vivekananda Engineering College, Kalavarai, Vizianagaram, India[2]

***Abstract*— This paper describes the simulation of HVDC system which is used to transfer bulk amount of power between two converter stations. The main aim of this paper is to reduce the power loss in the HVDC system. In order to reduce these power losses, we go for power flow control. The power flow control can be done by controlling the rectifier and inverter stations with Fuzzy Logic Controller.**

***Index Terms*— HVDC Transmission, Simulation, Fuzzy Logic Controller, Conventional controller.**

I. Introduction

All of the early HVDC schemes were developed using mercury arc valves. The introduction of thyristor valves was demonstrated in 1972 with the first back-to-back asynchronous interconnection at the Eel River between Quebec and New Brunswick. Since then thyristor valve technology has completely replaced mercury arc valve technology. By 2008, a total transmission capacity of 100,000 MW HVDC has been installed in over 100 projects worldwide, more than 25,000 MW HVDC is under construction in 10 projects, and an additional 125,000 MW HVDC transmission capacity has been planned in 50 projects[5]. To account for the rapid growth of DC transmission and its technology it is necessary to include the HVDC transmission into the undergraduate power systems curriculum. Most undergraduate curriculum have only one course on power systems which is typically devoted to AC transmission systems. The Electrical and Computer Engineering program at York College of Pennsylvania has four concentration areas: power systems/energy conversion, embedded systems, signal processing/communication, and control systems. In accordance with operational requirements, flexibility and investment, HVDC transmission systems can be classified into two-terminal and multiterminal HVDC transmission systems.

An HVDC transmission system consists of three basic parts:
1) A rectifier station to convert AC to DC
2) A DC transmission line and
3) An inverter station to convert DC back to AC.

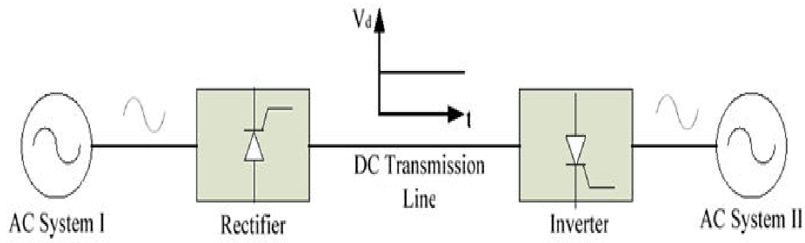

Fig 1. Schematic diagram of an HVDC transmission system

II. HVDC System Model

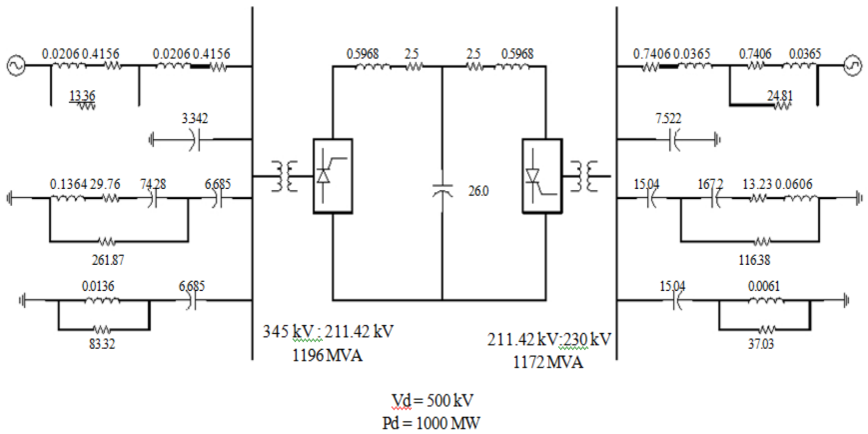

Fig 2. Schematic diagram of an HVDC transmission system

The linear dynamics of the system are expressed through continuous or discrete time-domain state-space equations. It also offers the flexibility of choosing from a variety of integration algorithms. The HVDC system shown in Fig.2. The system is a mono-polar 500-kV, 1000-MW HVDC link with 12-pulse converters on both rectifier and inverter sides, connected to weak ac systems (short circuit ratio of 2.5 at a rated frequency of 50 Hz) that provide a considerable degree of difficulty for dc controls. Damped filters and capacitive reactive compensation are also provided on both sides. The power circuit of the converter consists of the following sub circuits.

III. 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 PLO is used to build the firing signals. The output signal of the PLO is a ramp, synchronized to the phase-A commutating.

Following are the controllers used in the control schemes:

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

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1) 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 (due to a fault) or does not have sufficient load requirement (load rejection). 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 described earlier.

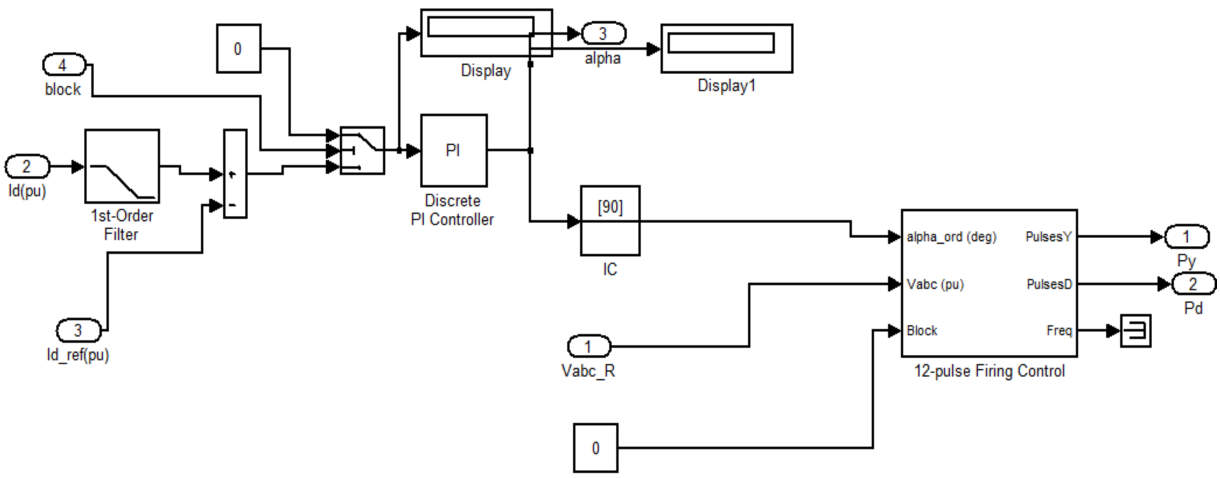

Fig 3. Rectifier control with PI.

2) 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) have 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.

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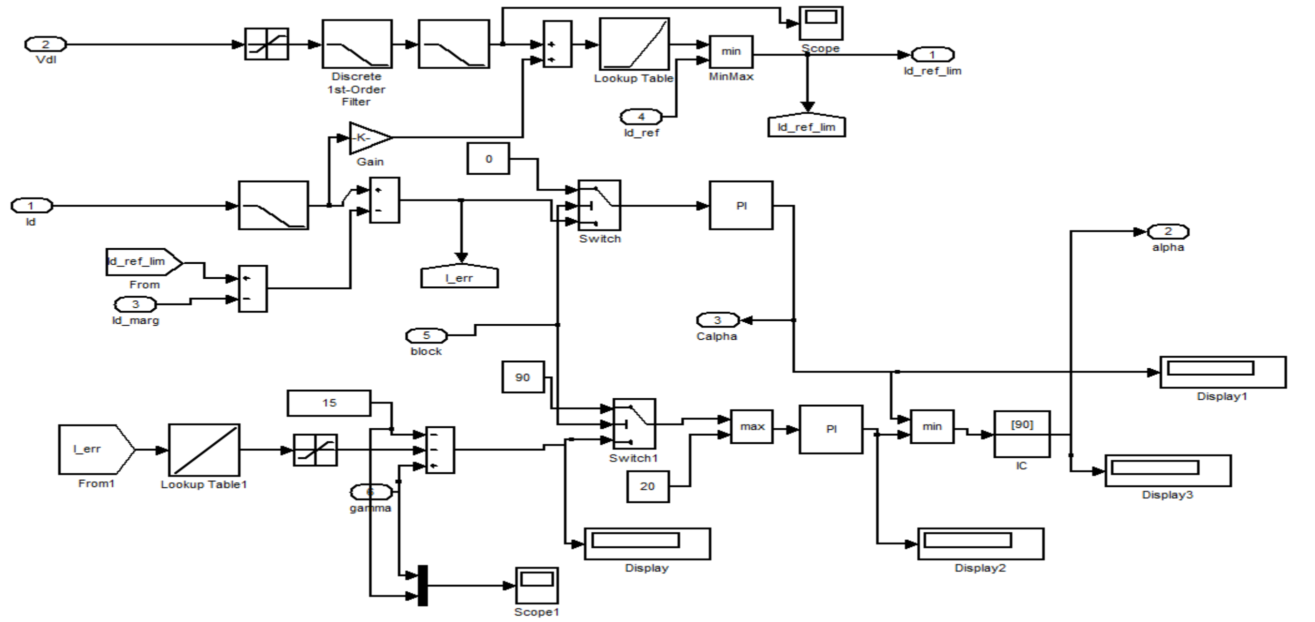


Fig 4. Inverter control with PI.

IV. SIMULATION RESULTS AND DISCUSSION

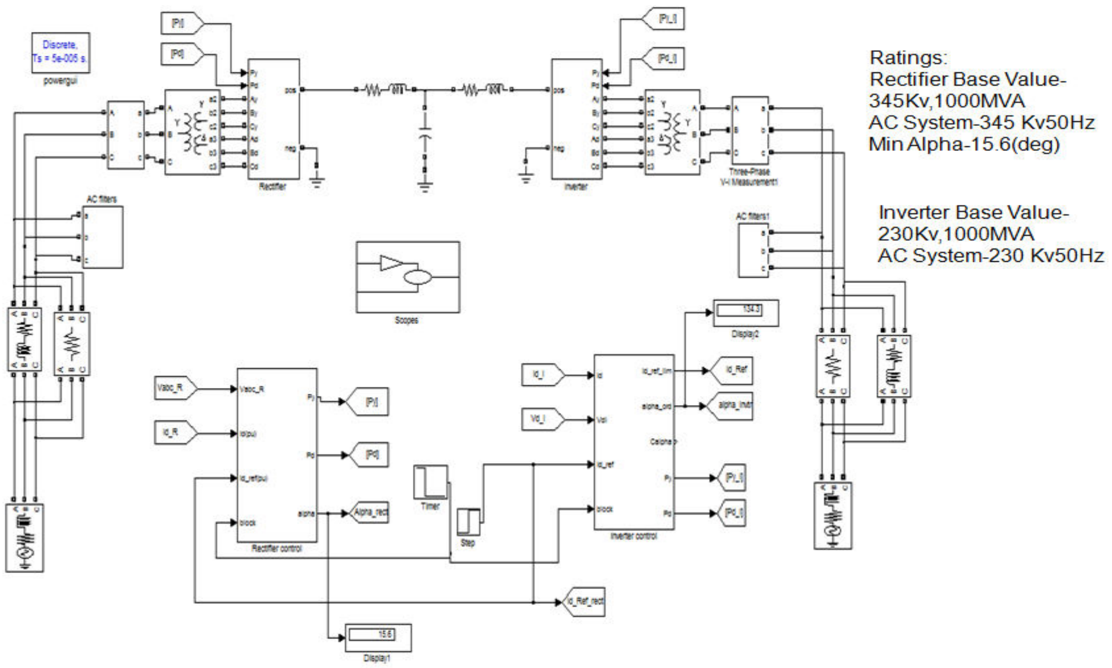
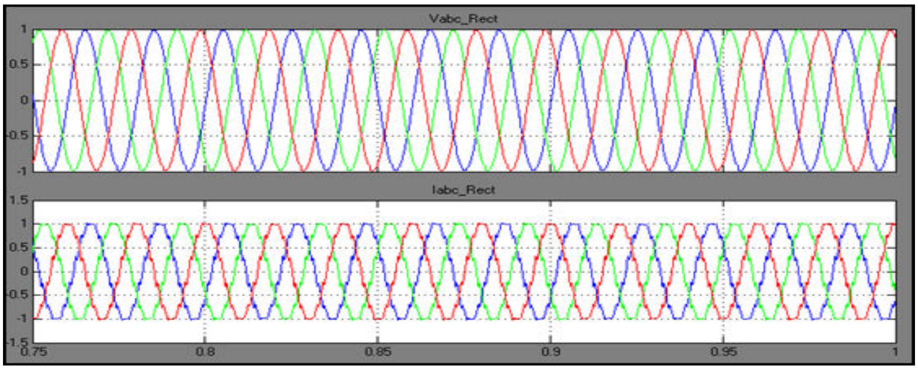
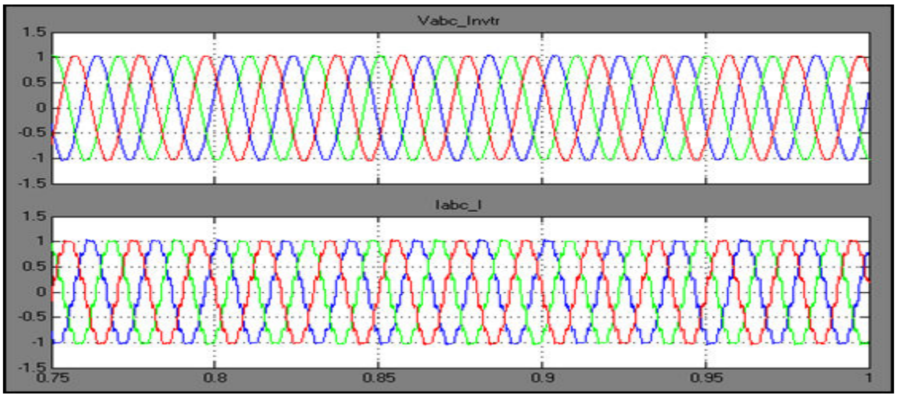


Fig 5. Simulink model of HVDC System



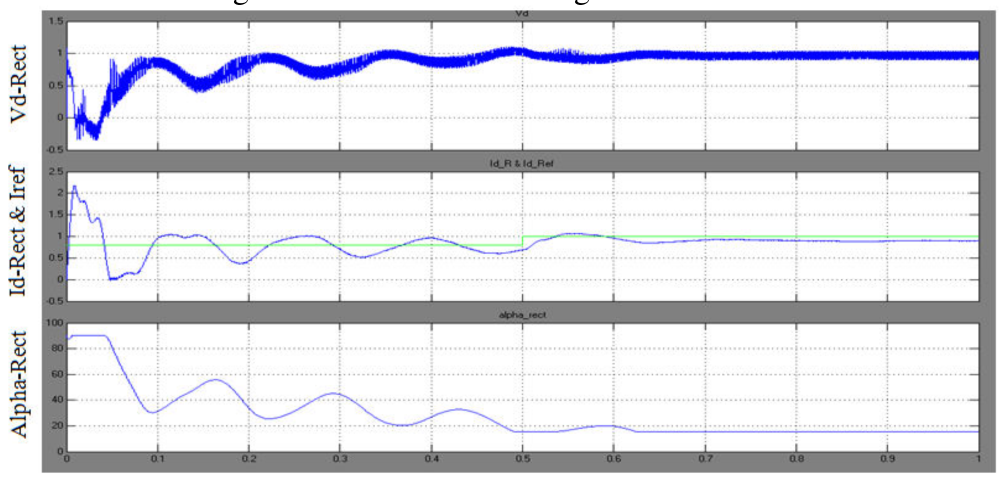
→ Time

Fig 6. Rectifier side AC Voltage ad AC Current



→ Time

Fig 7. Inverter side AC Voltage ad AC Current



→ Time

Fig 8. 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 (α=15.5 deg).

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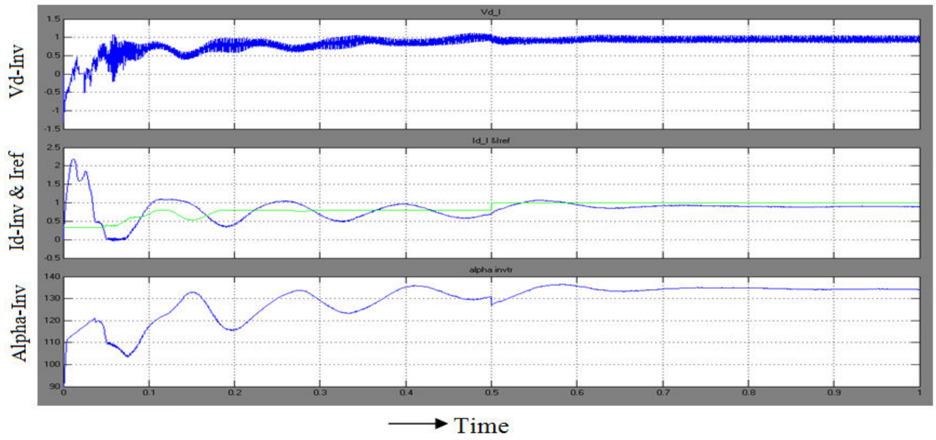

Fig 9. Inverter side DC Voltage, DC Current and firing angle order with PI

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

V. Design Of Fuzzy Logic Controller

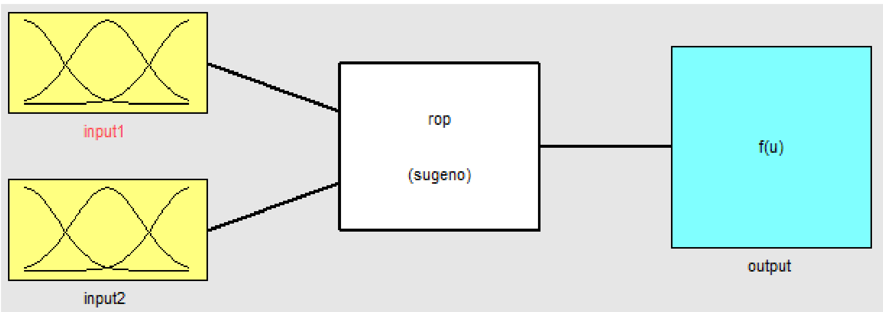

Fig 10. Fuzzy Inference System Editor.

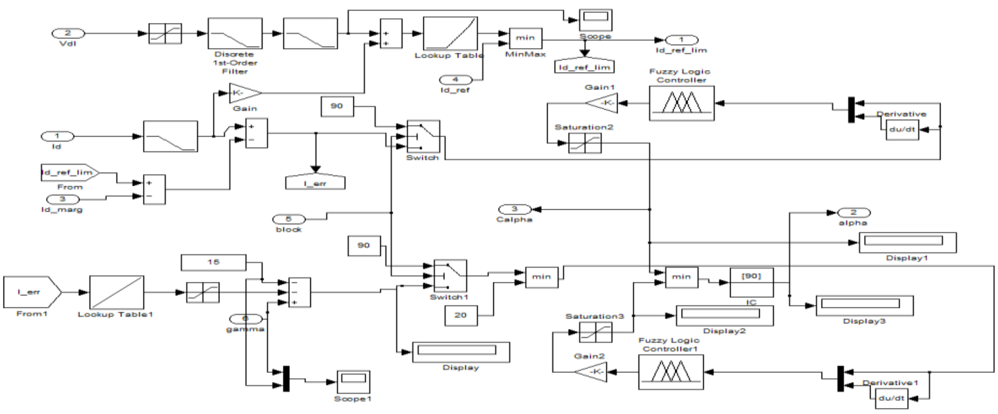

Fig 11. Inverter control with Fuzzy Logic Controller.

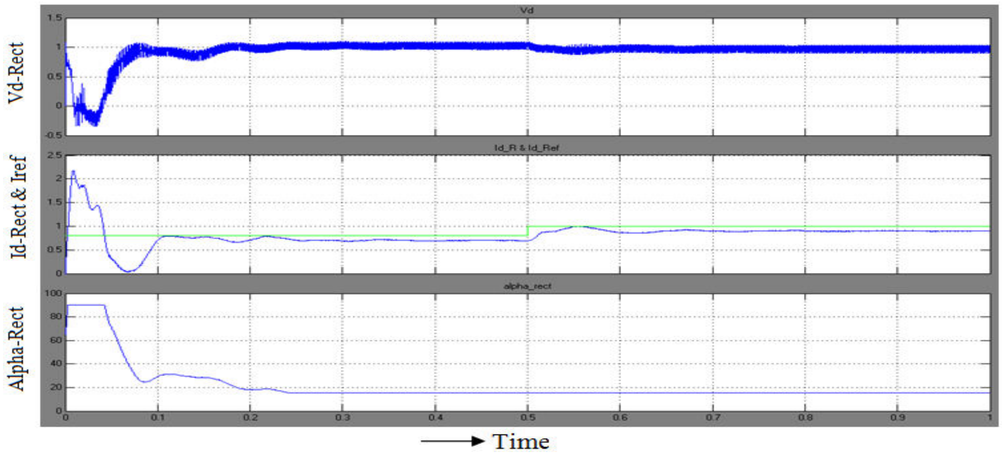

Fig 12. Rectifier side DC Voltage, DC Current and firing angle order with Fuzzy Logic Controller

From the above graph I_{d_R} and I_{d_Ref} are compared to produce an error signal which gives the firing angle order (α=15.5 deg).

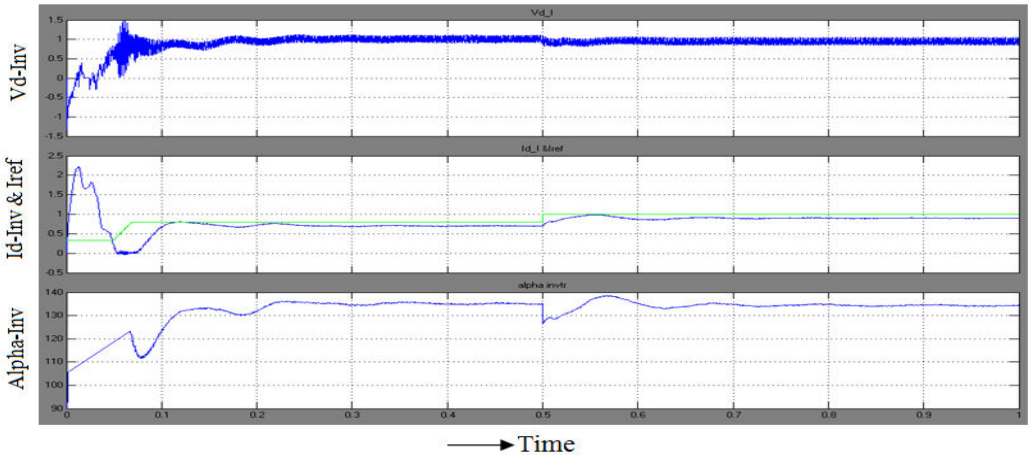

Fig 13. Inverter side DC Voltage, DC Current and firing angle order with Fuzzy Logic Controller

From the above graph I_{d_I} and I_{d_Ref} are compared to produce an error signal which gives the firing angle order(α_{inv}=142 deg).

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TABLE I
COMPARISON BETWEEN PI AND FUZZY LOGIC CONTROLLER FOR DIFFERENT FIRING ANGLES

Rectifier α (deg)	Inverter α (deg)		Id_R(p.u)		Id_I(p.u)		Vd_R(p.u)		Vd_I (p.u)	
	PI	FLC	PI	FLC	PI	FLC	PI	FLC	PI	FLC
15.5	134.3	142	0.8954	0.9030	0.8990	0.9024	1.0160	1.0190	0.8587	0.8690
30	128.6	130	0.8496	0.8520	0.8440	0.8480	0.8300	0.8350	0.8400	0.8470
45	119.4	120.5	0.6294	0.7530	0.6261	0.7340	0.7490	0.7840	0.6825	0.7020
60	109.9	112	0.3848	0.4520	0.3989	0.4320	0.3580	0.4680	0.3500	0.4520
75	98.62	101	0.2469	0.3010	0.2394	0.3120	0.2800	0.3210	0.2600	0.3120

From the above table, the DC currents and voltages of both rectifier and inverter with FLC shows better values when compared with PI controller for different firing angles.

TABLE II
EFFECT DUE TO CHANGE IN RECTIFIER FIRING ANGLE USING FLC

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	1.019	0.869
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

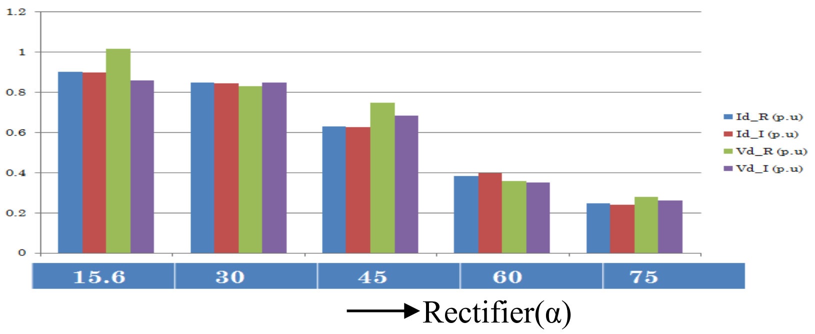

Fig 14. Effect due to change in Rectifier firing angle (chart representation) using FLC

VI. CONCLUSION

In this paper, a HVDC system is designed to control the power flow between two converter stations with conventional controller and Fuzzy Logic Controller. The simulation results shows that the HVDC system with Fuzzy Logic Controller have better power flow control when compared with PI controller for different firing angles.

APPENDIX I

HVDC System Data

Parameters	Rectifier	Inverter
AC Voltage Base	345 kV	230 kV
Base MVA	1000 MVA	1000 MVA
Transformer taps (HV side)	1.01 p.u.	0.989 p.u.
Nominal DC Voltage	500 kV	500 kV
Nominal DC Current	2 kA	2 kA
Transformer X_t	0.18 p.u.	0.18 p.u.
Source Impedance	R=0.4158Ω, L=0.0206 H	R = 0.7406 Ω, L = 0.0365 H
System Frequency	50 Hz	50 Hz
Nominal Angle	$\alpha = 15^0$	$\gamma = 15^0$

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