

Wind Farm Connected HVDC Link for Constant Power Flow Using Fuzzy Logic Controller

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Abstract:

Long distance AC transmission is often subjected to certain problems which limit the transmission capability. HVDC is a better option for transmission of power over long distances. Power is being transmitted between two generating stations via dc link. The control of power flow in DC link can be achieved through control of current or voltage. For minimization of loss considerations it is important to maintain constant voltage in link and adjust current to meet required power. In this project, a HVDC system is designed to control the power flow between two converter stations with conventional PI controller and Artificial Neural Networks. For rectifier side current control is used for inverter side both current and extinction angle control is implemented. 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. Here fuzzy logic controller is designed for both rectifier and inverter control and its performance is compared with conventional PI controller.

Keywords:

HVDC Transmission, Simulation, fuzzy, Conventional controller.

Introduction:

It is well known that the wind power generation has been sharing a large portion in the renewable energy market. Due to better wind condition, less restrictions, and more environmental concerns, most of wind farms are presently planned in offshore type for the transmission distance longer than 50 km to the nearest

grid connection point. The traditional HVDC classic technology is used to transmit power for long distances via overhead lines or submarine cables with reduced losses. There is a breakpoint between ac and dc transmission distance, where after this point dc transmission is smarter and efficient. It also reduces the synchronous constraints between the two ac systems. It enhances steady state and dynamic stability of the ac system. In recent 15 years a new technology, HVDC Light based on VSC (Voltage Source Converters) is used. HVDC Light has considerably higher dynamic performance compared to HVDC Classic, but still HVDC Classic is dominating for low cost bulk transmission. In accordance with operational requirements, flexibility and investment HVDC transmission systems are classified into two-terminal and multi terminal.

The first HVDC transmission in the world has begun in 1954. It was 150KV, 20MW DC link between Swedish main land and island of Gotland by ASEA. Until 1970, mercury valves are used for conversion of direct current. After a powerful invention of high power electronic device so called thyristor for static power transfer has been encouraged by power industries and its substantial increase of rating and reliability over the years. High and growing electricity demands needs the transmission of electrical power over long distances. Right-of way (ROW) and better efficiency are some of the challenges that have faced by 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 contest. The modern form of HVDC employs the technology that was developed and commercialized some 50 years ago by ABB (Asea Brown Boveri) company.

DC power transmission at low voltages has high losses over long distances, thus giving rise to High Voltage Alternating Current (HVAC) electrical systems. It was realized that for an ac system voltage conversion is simple with the development of a high power transformer. Further, a three phase synchronous generator is superior to a dc generator in every aspect. For these reasons ac technology was introduced at very early stage in the development of electrical power systems and it was soon accepted as the only feasible method of generation, transmission and distribution of electrical energy. However, some shortcomings in the HVAC transmission technology led to research into the application of HVDC transmission systems. With the development of high voltage valves, it became possible to transmit dc power at high voltages and over long distances, giving rise to HVDC transmission systems. This has grown tremendously in the recent years due to the fast development of modern solid state power electronic. For bulk power transmission over land, the most frequent HVDC transmission line is used.

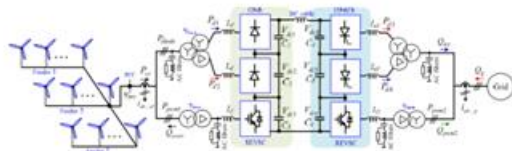


Fig 1. HVDC converter with the hybrid of VSC, diode and SCR rectifiers.

In a dc system, over voltages will occur at inverters, rectifiers and transmission lines during converter starting and shutting down operations, etc. The over voltages caused by those activities are referred to as internal over voltages. There are also external overvoltage's caused by lightning and switching. Lightning strikes pose a great danger to insulation. Although there are shielding systems that protect power systems against lightning strikes, direct strikes are still possible. Most lightning problems however, come through indirect strikes.

Long lines are exposed to overvoltages induced by internal and external phenomena.

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.

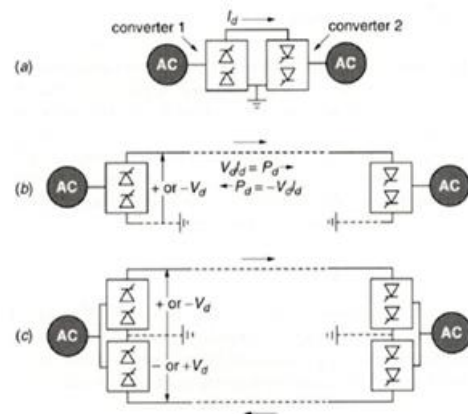


Fig 1. Schematic diagram of an HVDC back to back system system

II. CONVERTER STATION:

A converter station consists of basic converter unit, which primarily contains converter valve, converter transformer, smoothing reactor, AC filter, DC filter and so on. Basic converter units can be classified into 6-pulse converter unit and 12-pulse converter unit. Usually most HVDC schemes employ the 12-pulse converter as the basic converter unit. In order to form a 12-pulse converter unit, two 6-pulse converter units are connected in series on the DC side and in parallel on the AC side. AC/DC filters can be configured in accordance with the requirements of 12-pulse converter, there by greatly simplifying the number of filters, reducing land use and lowering the cost. A 12-pulse converter unit can employ the converter transformer of either two-winding or three-winding.

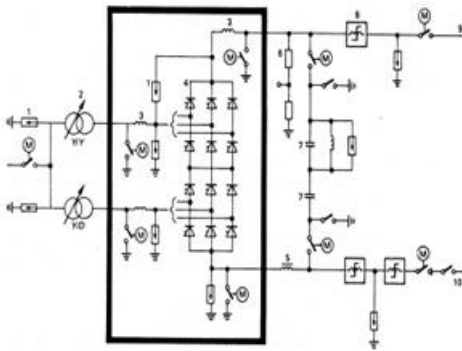


Fig2 The Main Circuit Diagram for One Pole of a Converter Station.

1. Surge Arrester
2. Converter Transformer
3. Air-Core Reactor
4. Thyristor Valve
5. Smoothing Reactor
6. Voltage Measuring Divider
7. DC Filter
8. Current Measuring Transducer
9. DC Line
10. Electrode Line

For a 12-pulse converter, the components are shown in Fig 4.1. In order to provide the 30° phase-shift for 12-pulse operation, the transformer valve-side windings must be connected in star-star and star-delta respectively. In order to limit any steep-front surges entering the station, a smoothing reactor is located on the DC side. The measuring equipments, such as voltage divider and current transducer, can provide the accuracy input signals for the control and protection systems. The switching components, such as isolators and circuit breakers, are used for the changeover from monopole metallic return to bipolar operation.

Fig 4.2 indicates the relative space of the various components for a bipolar converter station. The

areas of shunt capacitor banks and AC filter banks are the major proportion of the entire area and the valve hall and control room only take a small fraction of the total station area.

III. RECTIFIER AND INVERTER CONTROLS:

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).

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.

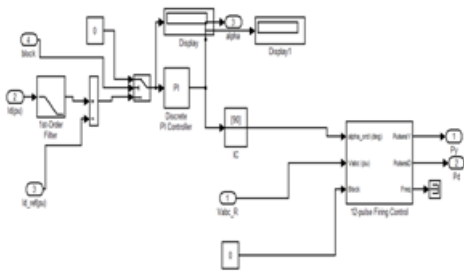


Fig 3. Rectifier control with PI.

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.

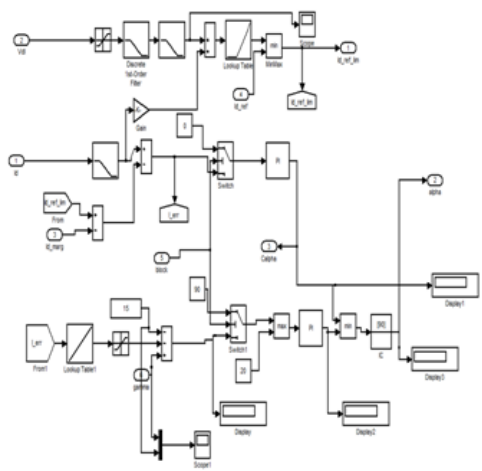


Fig 4. Inverter control with PI.

IV. SIMULATION RESULTS AND DISCUSSION

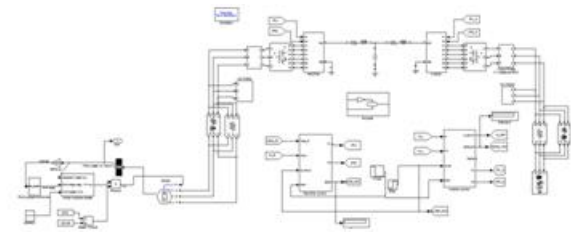
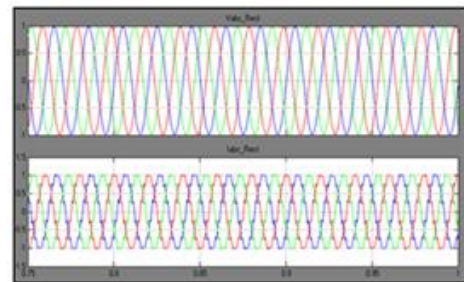
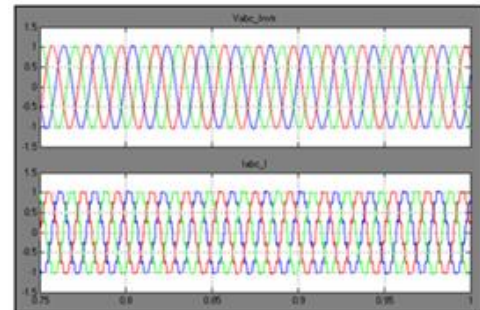


Fig 5. Simulink model of HVDC System with wind input



Time →

Fig 6. Rectifier side AC Voltage and AC Current



Time →

Fig 7. Inverter side AC Voltage and AC Current

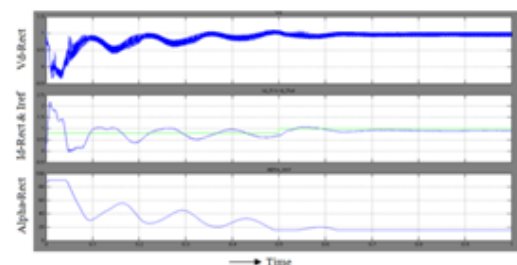


Fig 8. Rectifier side DC Voltage, DC Current and firing angle order with PI

From the above graph $I_{d,R}$ and $I_{d,Ref}$ are compared to

produce an error signal which gives the firing angle order ($\alpha=15.5$ deg).

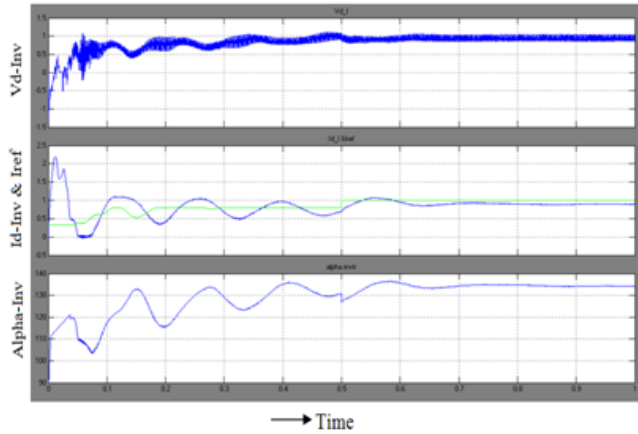


Fig 9. Inverter side DC Voltage, DC Current and firing angle order with PI

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

V. DESIGN OF FUZZY LOGIC CONTROLLER:

The logic of an approximate reasoning continues to grow in imace due to inaccessibility of the system or for comfort reasons. In this work a fuzzy remote controllers is developed for speed control of a converter fed dc motor. The performance of the fuzzy controller is compared with conventional P-I controller.

Fuzzy in power systems:

There are many fuzzy concepts in power systems associated with the mentioned uncertainty. Ex: Power System Stability, which is a very important issue in Power System Operation. A Power System is either stable or unstable. There is nothing Fuzzy about this. However if the system is stable, we need to describe its degree of relative stability using terms such as lightly damped highly damped over damped etc. If the system is unstable we may have to refer thus to small disturbance instability, dynamic instability, and

Transient in stability or voltage instability. It is obvious that the concept “stability” is quite Fuzzy.

3.6 Fuzzy system:

The fuzzy interface system Fuzzy system basically consists of a formulation of the mapping from a given input set to an output set using Fuzzy logic. The mapping process provides the basis from which the interference or conclusion can be made.

Implication method:

The implication step (3) was introduced for the evaluation of individual rules.

Methods:

- 1) MAMDANI
- 2) SUGENO
- 3) LUSING LARSON.

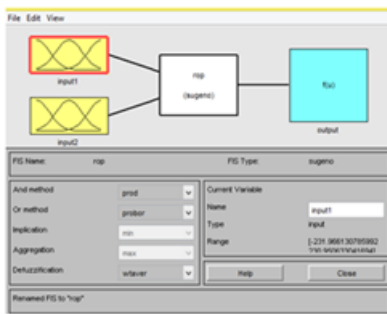
Mamdani:

Mamdani, one of the pioneers in the application of ‘FL’ in control systems, proposed this implication method. This Mamdani method is most commonly used method. The outputs of the Mamdani method is truncated Signals of the inputs; this output is depending on the minimum values in the inputs.

Ex: If X is zero (ZE) AND y is positive (PS) Then Z is negative.

Sugeno:

The sugeno or Takgi-Sugeno-Kang method of implication was first introduced in 1985. The difference here is that unlike the Mamdani and Lusins Larson methods, the output MFS are only constants or have linear relations with the inputs with a constant output MF(Singleton), it is defined as the Zero-order Sugeno method; whereas with a linear relation, it is known as first order Sugeno method. The outputs of the sugeno method have a constant minimum value in the input.



Fuzzy fis system Fig 13. fuzzy logic controller

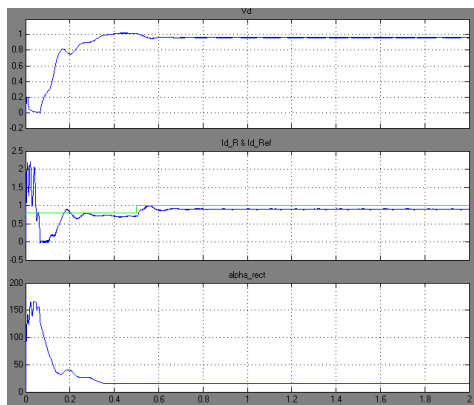
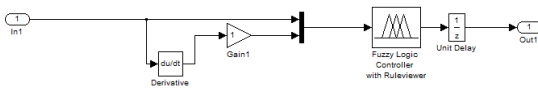


Fig 14. Rectifier side DC Voltage, DC Current and firing angle order with fuzzy

From the above graph $I_{d,R}$ and $I_{d,Ref}$ are compared to produce an error signal which gives the firing angle order ($\alpha=15.5$ deg).

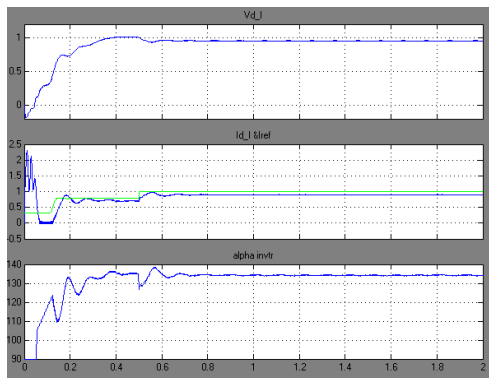
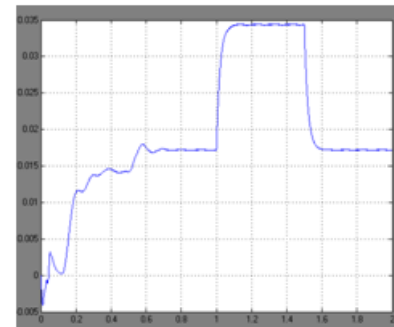


Fig 15. Inverter side DC Voltage, DC Current and firing angle order with fuzzy

From the above graph $I_{d,I}$ and $I_{d,Ref}$ are compared to produce an error signal which gives the firing angle order ($\alpha_{inv}=142$ deg).



Power output with fuzzy controller

Conclusion:

A novel converter topology for the HVDC transmission system integrating the offshore wind farm with the AC grid has been proposed in this research, where the VSC with the diode and the SCR converters are connected in series. Due to utilizing the diode and SCR devices, the total cost, losses, and maintenance requirement of the HVDC converter system can be much reduced. 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 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_r	0.18 p.u.	0.18 p.u.
Source Impedance	$R=0.4158\Omega, L=0.0206H$	$R=0.7406\Omega, L=0.0365H$
System Frequency	50 Hz	50 Hz
Nominal Angle	$\alpha=15^\circ$	$\gamma=15^\circ$

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