Enhancement of AC System Stability using Artificial Neural Network Based HVDC System

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Abstract - *With growing industrialization, power generation and demand are increasing very fast. To handle large bulk amount of power, AC power transmission is not economical over long distances. High Voltage Direct Current (HVDC) transmission is the only alternative to it. The advantages gained by DC power transmission outweigh the complexity of its operation and maintenance. HVDC transmission systems, when installed, often form the backbone of an electric power system. They combine high reliability with a long useful life. Their core component is the power converter, which serves as the interface to the AC transmission system. The conversion from AC to DC, and vice versa, is achieved by controllable electronic switches (valves) in a 3-phase bridge configuration. This paper is concerned with the design and optimization of intelligent controller (particularly ANN) for a HVDC system.*

A MATLAB program has been developed to simulate the system operation. Various simulation results are presented under steady state conditions and performance of ANN and PI controllers is compared. Simulation results obtained shows that the performance of ANN controller is found to be better than PI controller. PWM pattern generation is based on carrier less hysteresis based current control to obtain the switching signals to the Voltage source power converter.

Key Words: High voltage direct current, Voltage Dependent Current Order Limiter, Current Control Amplifier, Artificial Neural Network, Voltage Control Amplifier

1. Introduction

HVDC transmission refers to the AC power generated at a power plant is transformed into DC power before its transmission. At the inverter (receiving side), it is then transformed back into its original AC power and then supplied to each household. Such power transmission method makes it possible to transmit electric power in an economic way through up-conversion of voltage, which is an advantage in existing AC transmission technology and to overcome many disadvantages associated with AC power transmission as well. The overall structure of an HVDC system is shown in Figure 1.
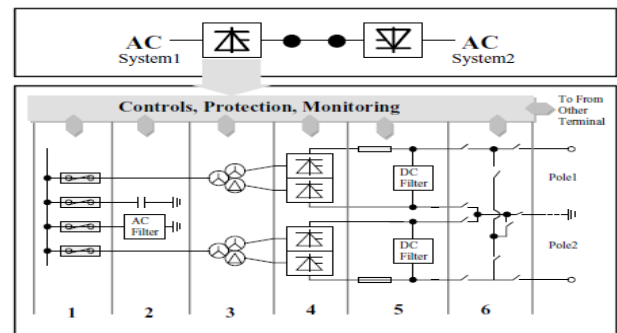

Figure 1: Overall HVDC transmission system

Figure 2 represents the overall components of HVDC system used. In this model, two 6-pulse converters are connected in series (bipolar 6-pulse converter) instead of a 12 pulse converter. In a real system, 12 pulse converters are used but bipolar 6-pulse converter is used here for simplicity and ease of computation.
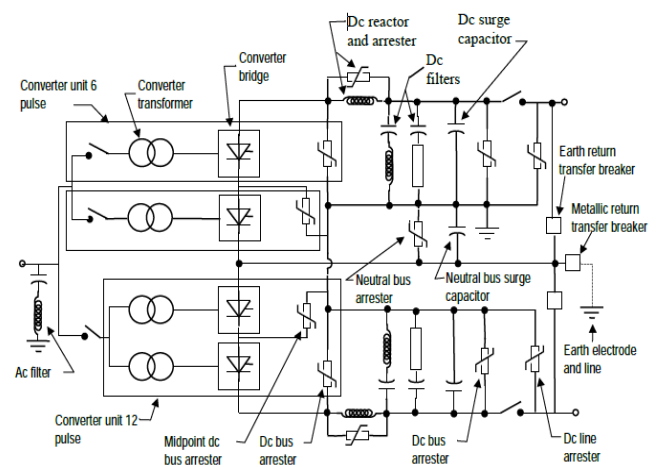

Figure 2: HVDC substation with its basic components

1.1 HVDC Controller Structure

Figure 3 shows the basic control diagram of an HVDC system. An HVDC system can be divided into several levels. Master control determines the power order or frequency order and calculates the current order for both poles. Then, the current order that was received from master control is modified by control functions and limits in pole control. Valve group control consists of a converter control and a valve firing control. The converter control includes the current controller. The valve firing control distributes the firing signal to all thyristors.
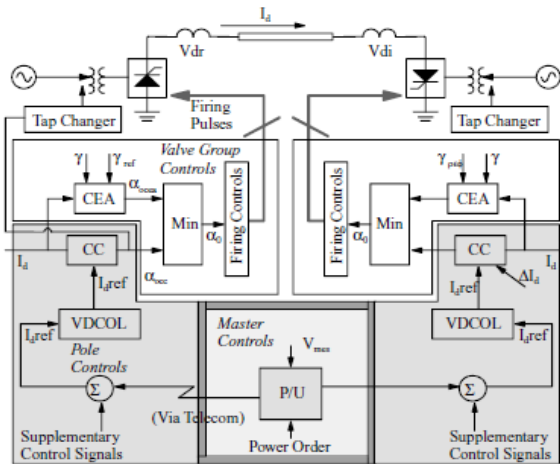

Figure 3: Basic control diagram of an HVDC system

2. CONVERTER CONTROL TECHNIQUES

HVDC transmission systems must transport very large amounts of electric power which can only be accomplished under tightly controlled conditions. DC current and voltage is precisely controlled to effect the desired power transfer. It is necessary therefore to continuously and precisely measure system quantities which include at each converter bridge, the DC current, its DC side voltage, the delay angle α and for an inverter, its extinction angle γ.

 Two terminal DC transmission systems are the more usual and they have in common a preferred mode of control during normal operation. Under steady state conditions, the inverter is assigned the task of controlling the DC voltage. This it may do by maintaining a constant extinction angle γ which causes the DC voltage to droop with increasing DC current as shown in the minimum constant extinction angle γ characteristic A-B-C-D in Figure 4. The weaker the AC system at the inverter, the steeper the droop.
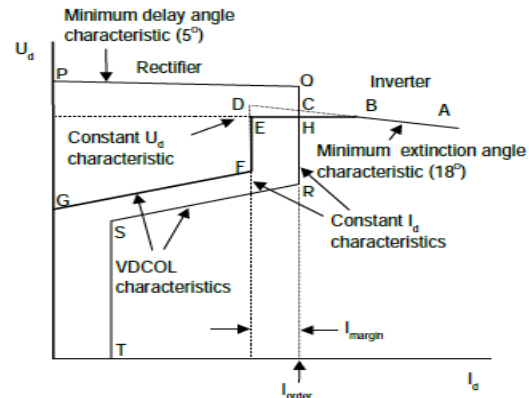

Figure 4: Steady state - characteristics for a two terminal HVDC system

Alternatively, the inverter may normally operate in a DC voltage controlling mode which is the constant characteristic B-H-E in Figure 4. This means that the extinction angle γ must increase beyond its minimum setting depicted in Figure 4 as 180°. If the inverter is operating in a minimum constant γ or constant characteristic, then the rectifier must control the DC current I_d. This it can do so long as the delay angle α is not at its minimum limit. The steady state constant current characteristic of the rectifier is shown in Figure 8 as the vertical section Q-C-H-R, where the rectifier and inverter characteristic intersect, either at points C or H, is the operating point of the HVDC system.

The operating point is reached by the action of on-line tap changers of the converter transformers. The inverter must establish the DC voltage U_d by adjusting its on-line tap changer to achieve the desired operating level if it is in constant minimum γ control. If in constant U_d control, the on-line tap changer must adjust its tap to allow the controlled level of U_d be achieved with an extinction angle equal to or slightly larger than its minimum setting of 180° in this case.

The on-line tap changers on the converter transformers of the rectifier are controlled to adjust their tap settings so that the delay angle has a working range at a level between approximately 100 and 150 for maintaining the constant current setting. If the inverter is operating in constant DC voltage control at the operating point H, and if the DC current order is increased so that the operating point H moves towards and beyond point B, the inverter mode of control will revert to constant extinction angle γ control and operate on characteristic A-B. DC voltage will be less than the desired value, and so the converter transformer on-line tap changer at the inverter will boost its DC side voltage until DC voltage control is resumed.

Not all HVDC transmission system controls have a constant DC voltage control such as is depicted by the

horizontal characteristic B-H-E in Figure 4. Instead, the constant extinction angle control characteristic A-B-C-D and the tap changer will provide the DC voltage control.

2.1 HVDC Control

Normally, HVDC system operates in constant power control mode. Power order is given by the user. Current order () derived from the power controller, which is send to the VDCOL (Voltage Dependent Current Order Limiter) and into the Current Control Amplifier (CCA). The alpha order from the CCA is send to the converter firing control which determines the firing instant of valves.

Figure 5 shows HVDC control overview.
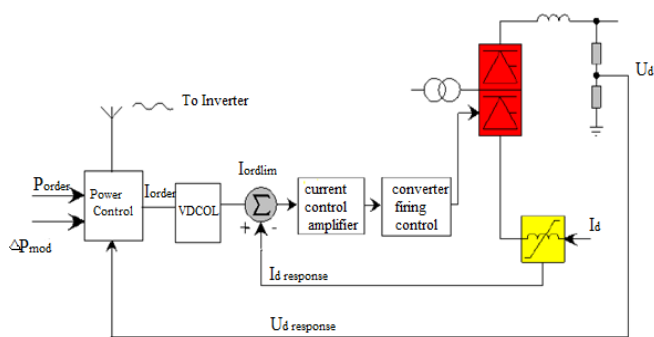
Figure 5: HVDC control overview

The primary function of HVDC controls are:
- Fast and flexible power control between the terminals under steady state and transient operation.
- Better stability of AC system.
- Fast protection of AC and DC system faults.
- Minimizes over voltage across the valves.
- Reduces the short circuit current through the valves and lines/cables
- Reduces the reactive power consumption.
- Avoids repetitive commutation failures.

The above advantages are achieved by varying exact firing instant of valves. The converter firing control determines the firing instants for each valve to obtain the rated DC voltage. The input for the firing control system could be the output of current control, voltage control, minimum alpha control and minimum commutation margin control mode.

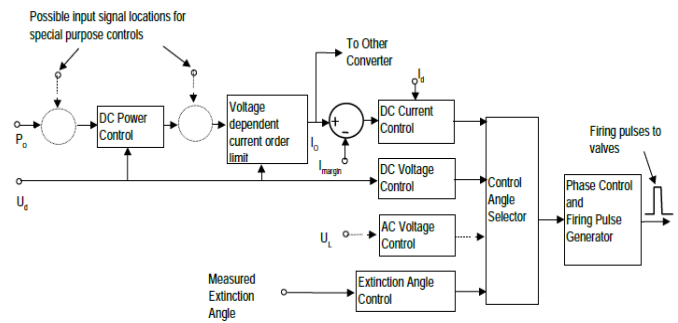The layout of HVDC system is shown in the Figure 6 below:

Figure 6: HVDC control system layout

Constant voltage control is normally used under reduced voltage operation; the is set to higher value at normal voltage operation to avoid hunting between alphamax and Voltage controller. But in reduced voltage operation shall be reduced to nominal reduced voltage. Figure 7 shows Overview of HVDC regulator.
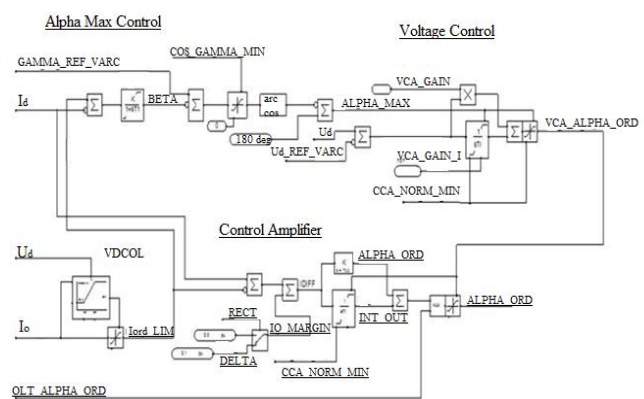

Figure 7: Overview of HVDC regulator

2.2 Voltage Dependent Current Order Limiter (VDCOL)

Figure 8 shows control diagram of Voltage Dependent Current Order Limiter (VDCOL).
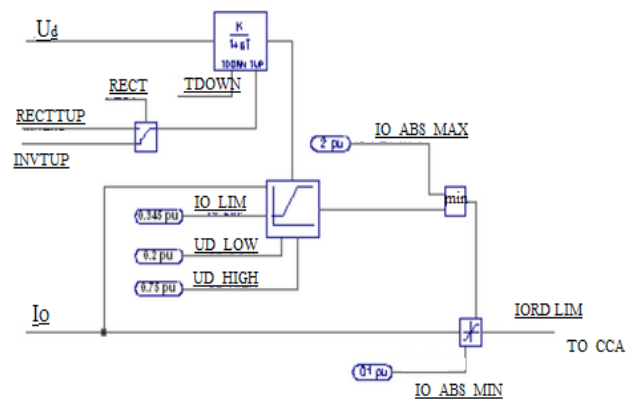

Figure 8: Voltage Dependent Current Order Limiter

The main function of VDCOL control is to reduce the current order to lower value when there is a reduction in DC voltage due to contingencies, in order to prevent the higher consumption of reactive power and valve voltage stress. If the system is operating in constant power control mode, current would be increased to maintain the constant power at low voltage causes higher consumption of reactive power will decrease the AC voltage further and induce commutation failure during the recovery of DC system. The break points for DC voltages are typically between 70% and 30%. These breakpoints could vary relative to the strength of the AC system. Normally, the long lines have same. High breakpoints for both rectifier and inverter but in contrast long cables need different. High break points for charging the cable i.e., 50% for rectifier and 90% for inverter.

If there is fault in the inverter end, voltage would decrease greatly, if the VDCOL is not activated, the power control mode will increase the current to keep the power constant. Increased current will increase the reactive power consumption of converter; it will increase the risk of subsequent commutation failures if the AC system is relatively weak. The low pass filter time constants $U_d\_T_c\_Dn$ and $U_d\_T_c\_Up$ are down time and up time delay of break point limits. The down time for the inverter should be fast to prevent commutation failures but for rectifier it need not be too fast during inverter fault there is a threshold limit for VDCOL (0.8), if the DC voltage reaches threshold value; current order is decreased very rapidly to predefined lower value to prevent the consecutive commutation failure during inverter side AC fault.

The down time constant could be same for both stations. But the up time constant could not be, rectifier should restart before the inverter. So, the up time constant for inverter should be higher than rectifier (mostly depends upon how strong the AC system is). Contrary, if the inverter restarts first, it starts building the counter voltage and thus the DC current, might lose the current margin causing power reversal. This function prevents the commutation failure during the recovery. Obviously the valve stress is reduced.

The output of voltage regulator is used as maximum and minimum limits of current control amplifier with respect to converter (rectifier/inverter). In normal voltage operation, the reference voltage of the voltage regulator is set above the operating voltage in order to avoid the hunting between normal tap changer controller and voltage controller. The output from the voltage and angle reference calculation has multiplied by factor of one tap changer step for inverter voltage. This reference voltage is sent as input for voltage regulator. Even higher reference value shall be used in rectifier voltage controller in order to de-activate if it is active at inverter station. Figure 9 shows block diagram of combined CCA and VCA.
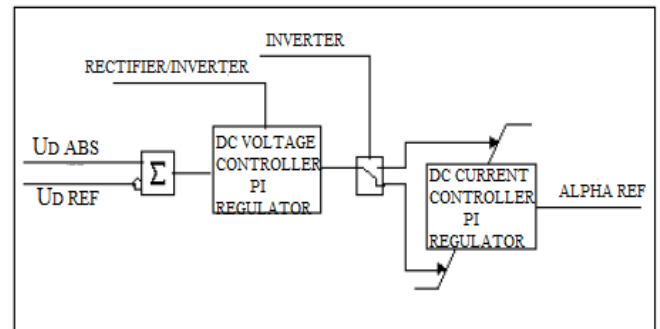

Figure 9: Combined CCA and VCA

3. Artificial Neural Network Controller

Artificial Neural Networks (ANNs) are gaining widespread application in several areas of engineering, especially where, due to non-linearity of the process, it is often too cumbersome to analyze the process or the plant under study. The ANN has the capability to learn and extract information in systems where the non-linearity and time dependency do not permit one to use methods such as frequency or modal analysis. Although it is always possible to linearise such a system around an operating point and conduct such studies, derived models always remain valid only within the limited region.

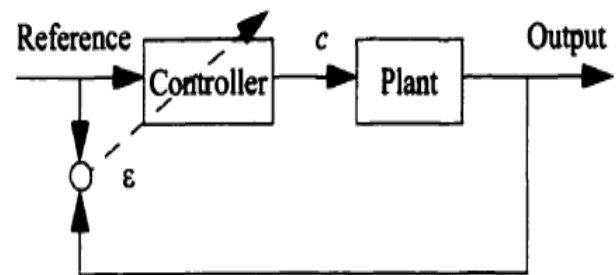The controller implementation is shown in figure 10.

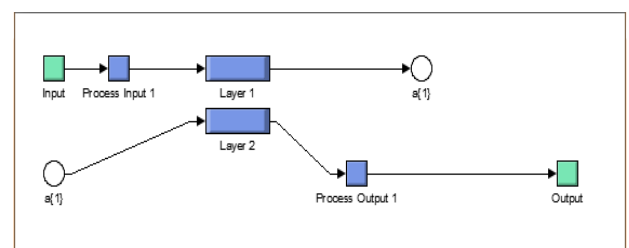
Figure 10: Controller Implementation
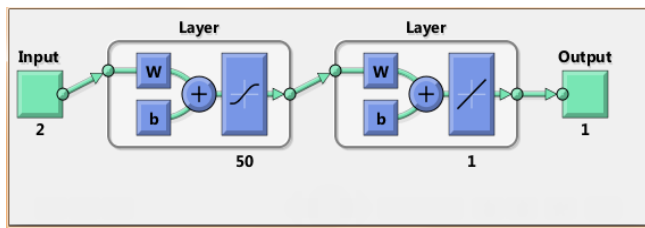

Figure 11: ANN Network Layers

Figure 12: ANN network with hidden and output layers

The number of hidden neurons in an ANN is one of the main characteristics of the system. The number of neurons in an ANN determines the total number of unknowns in the network. The larger the number of neurons, the more time consuming and lengthy is the learning process.

4. Simulation & simulation result

The system is a mono-polar 500-kV, 1000-MW HVDC link with 12-pulse converters on both rectifier and inverter sides and connected to weak AC system (short circuit ratio of 2.5 at a rated frequency of 50Hz) that provides a considerable degree of difficulty for DC controls. AC filters are added to absorb the harmonics generated by the converter as well as to supply reactive power to the converter. The simulation of CIGRE HVDC Benchmark System is carried out in MATLAB-SIMULINK. Figure 13 shows SIMULINK diagram of HVDC 12-pulse transmission system.
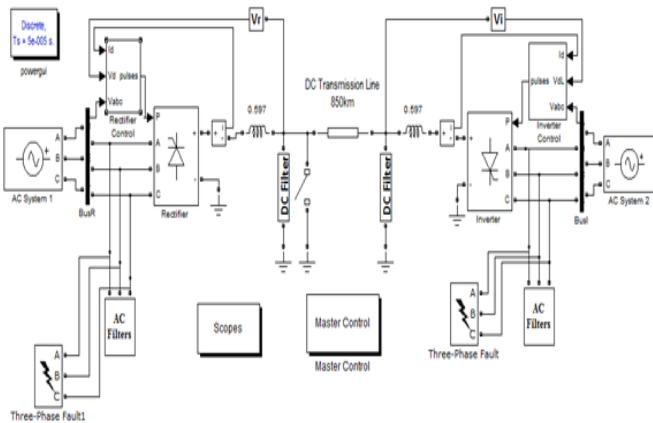

Figure 13: SIMULINK diagram of HVDC 12-pulse transmission system

4.1 Simulation Results without Fault Condition

Figure 14 and Figure 15 shows the system voltage and current waveforms under no fault condition at the rectifier side using PI and ANN controllers. Figure 16 and Figure 17 shows the system voltage and current waveforms under no fault condition at the inverter side using PI and ANN controllers. Figure 18 shows Power response under no fault condition.
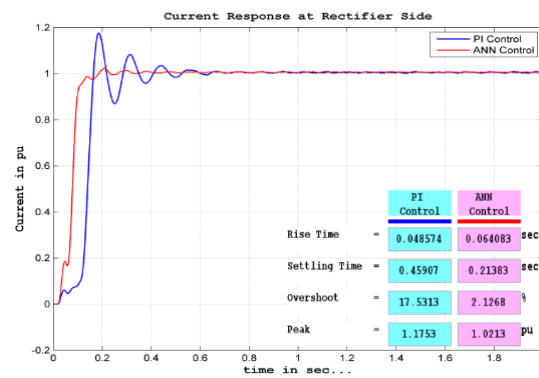

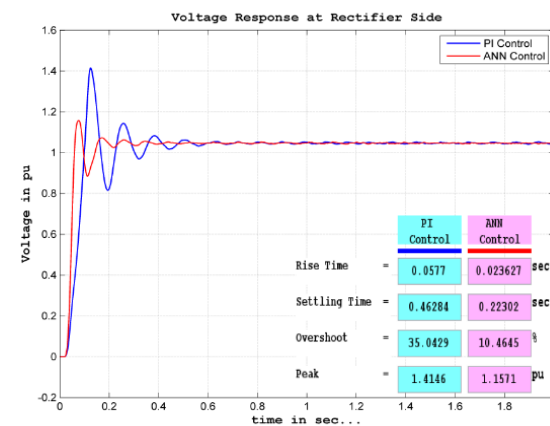Figure 14: Current response of PI & ANN controllers under No fault condition at the rectifier

Figure 15: Voltage response of PI & ANN controllers under No fault condition at the rectifier
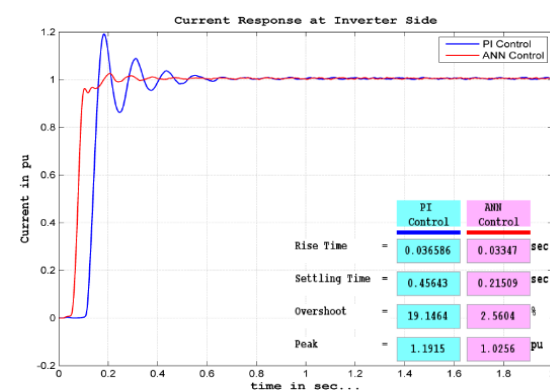

Figure 16: Current response of PI & ANN controllers under No fault condition at the inverter
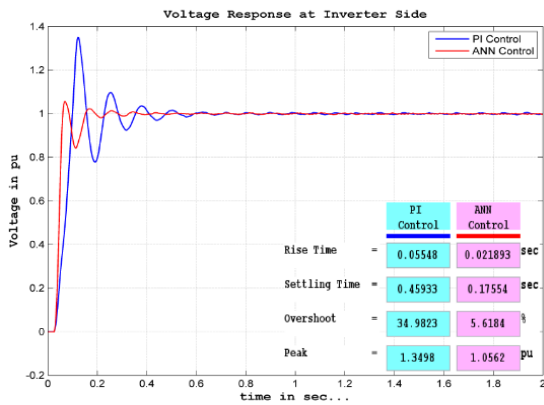
Figure 17: Voltage response of PI & ANN controllers under No fault condition at the inverter
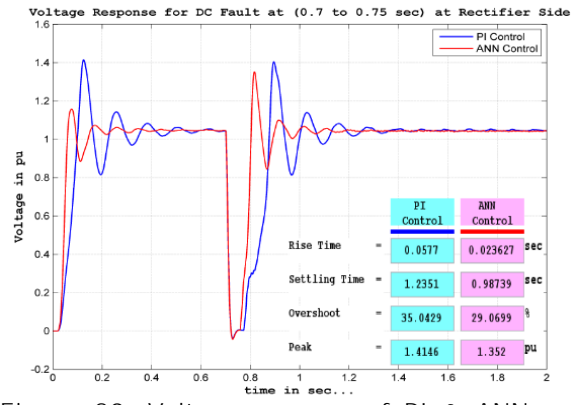

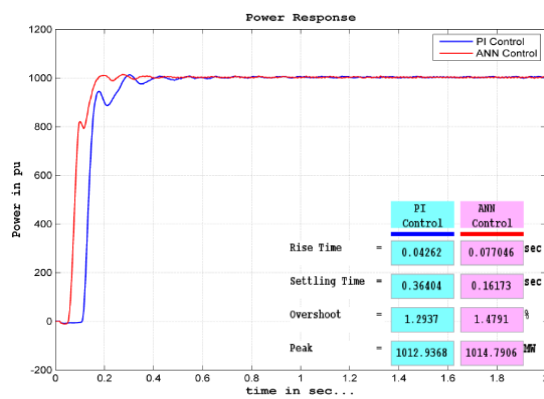Figure 20: Voltage response of PI & ANN controllers under DC fault condition at the rectifier

Figure 18: Power response of PI & ANN controllers under No fault condition
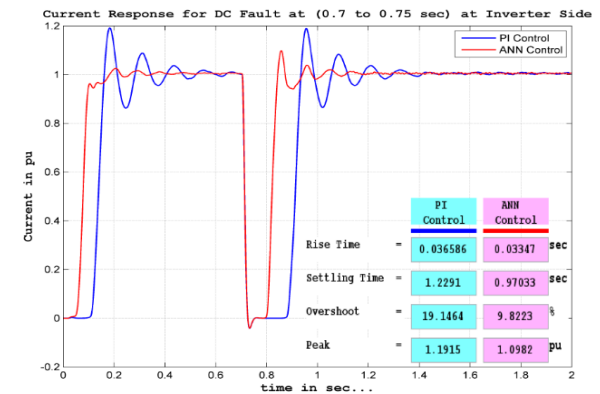

Figure 21: Current response of PI & ANN controllers under DC fault condition at the inverter

4.2 Simulation Results with DC Fault

Figure 19 and Figure 20 shows the system voltage and current waveforms under DC fault condition at the rectifier side using PI and ANN controllers. Figure 21 and Figure 22 shows the system voltage and current waveforms under DC fault condition at the inverter side using PI and ANN controllers. Figure 23 shows the Power response for DC fault.
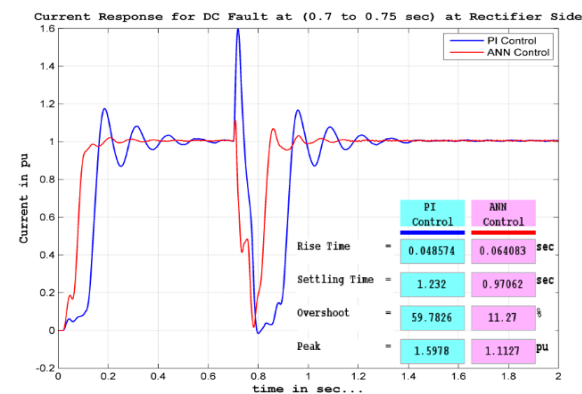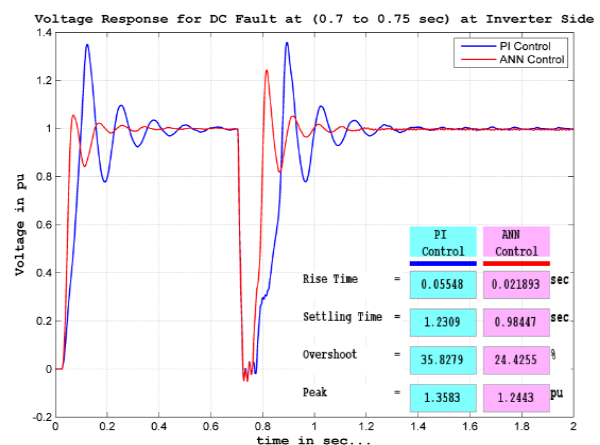

Figure 20: Voltage response of PI & ANN controllers under DC fault condition at the inverter

Figure 19: Current response of PI & ANN controllers under DC fault condition at the rectifier
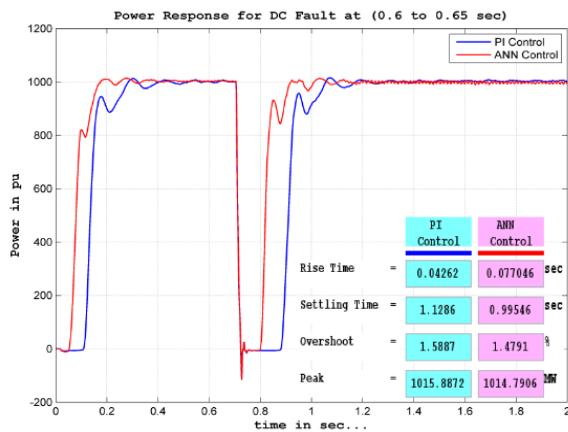
Figure 21: Power response of PI & ANN controllers under DC fault condition

5. CONCLUSIONS

A HVDC system is designed to control the power flow between two converter stations with 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 an 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, Artificial Neural Networks is designed for both rectifier and inverter control and its performance is compared with conventional (PI) controller.

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