

# Neural Network–Assisted Harmonic Reduction and Power Quality Enhancement in Vsc-Hvdc Links

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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 VSC+HVDC 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 Artificial Neural Networks is designed for both rectifier and inverter control and its performance is compared with conventional PI controller.**

**Keywords - HVDC Transmission, Simulation, Artificial neural networks, Conventional controller, THD.**

## I. INTRODUCTION

Electrical energy is a universal commodity available throughout the world and regarded as a daily consumer need [1]. The sources of renewable energies like solar, wind, etc are used to support the primary demand of energy.

The intermittency of the renewable sources, reactive power issues and harmonics stop the performance of the power system by causing problems of power system stability [2], [3]. Flexible AC Transmission Systems (FACTS) devices are commonly incorporated to compensate reactive power, regulate voltage stability and improve power quality [4], [5]. FACT devices, however, also change different system parameters [6], so as to study the quality of power and determine the causes and solutions to these issues of power quality.

In power systems, power quality has a major role during supply of variable power to the load. Consequently, the customers of domestic and industrial with sensitive loads will get affected by poor power quality. When any disturbance occurs in

load voltage, results in voltage transient, sag, swell, harmonics causing high distortions and Harmonics causing Total Harmonic Distortion (THD).

The DVR can control the voltage from these problems and protect against tripping and resulting losses. Various problems and solutions related to DVR were reported, such as balanced voltage in a three-phase system and energy optimized DVR control [7]. References [8], [9] give analysis of various control strategies for different voltage sag types.

In [10] a comparison is presented for DVR between various topologies and control techniques. Paper [11] discusses the design of a DVR supported by a capacitor that protects distortions, sags, swells, or imbalances in supply voltages. The DVR's performance is discussed in [12] with a transformer of high frequency-link. This paper presents DVR's control and its performance with voltage source converter (VSC). In this paper synchronous reference frame (SRF) theory with artificial neural network (ANN) controller is used for DVR control.

## II. THE STATE OF HVDC TECHNOLOGIES

Developments in advanced power electronic devices and fully-controlled semiconductors have had an immense impact on the development of HVDC technology. As a result, HVDC is now one of the best transmission solutions for the transfer of bulk power over long distances [1] and has been increasingly used in many parts of the world, such as China and India, where energy resources are dispersed a great distance from the load centres. In addition, a greater level of interconnection provides greater diversity of potential supplies, which helps with intermittency issues posed by renewable generation and consequently the security of the electricity supply. It also facilitates competition in the European market and assists in the transition to a low-carbon energy sector by integrating various renewable sources.

### Primary advantages of HVDC links over HVAC lines

#### The primary advantages [2] of HVDC links over HVAC links are:

- The elimination of reactive power for power transmission purposes. Power can be transferred over long distances with constant voltage at the receiving end and therefore can enable full utilisation of the conductors for active power transmission. When using long AC cables, compensating devices such as SVCs or STATCOMs are required to maintain the allowed AC voltage level.
- Higher power transfer with the same size and insulation level of DC lines compared to AC lines. The effective voltage can be higher and the wires can be larger (wire diameter is limited for AC lines due to the skin effect whereas a DC line can accommodate any diameter).
- Lower losses on DC lines, however, for total loss calculation, HVDC converter stations must be taken into account as well.
- HVDC links allow for bars of asynchronous AC grids to be connected; they then can be used for market purposes as well as for system support by means of ancillary services. In general, there is no need for a parallel interconnected AC grid.
- As explained above, HVDC overhead lines can transport significantly more power for the same

size compared to HVAC lines. This allows for smaller cable sizes in the DC system, therefore the required ground area and support towers are smaller.

- System operations can actively control the power flow. This is due to the fact that HVDC links can rapidly control the transmitted power. This may be challenging from an operational point of view, however, an adequate complementary control system can be used along with the HVDC lines in a coordinated manner to support system operation, for example, by reducing the number of required remedial actions for assuring system security as well as by improving transient stability and damping oscillations in the power system. This in turn will allow the system operator to utilize the existing AC network more efficiently.

### Typical applications of HVDC links

#### Interconnecting two asynchronous AC systems or two AC systems with different frequencies:

HVDC has the ability to interconnect two separate asynchronous AC systems as a tie line, for example, where one operates at a frequency of 50 Hz and the other at 60 Hz (such as the back-to-back 500 MW HVDC link between Uruguay and Brazil) or where the two systems operate at the same frequency but different phase angles (such as the back-to-back HVDC link connecting the asynchronous Eastern and Western American system and many HVDC connections between central Europe and the Nordic region). This is primarily because DC power is independent of the frequency and phase angle of the AC system.

Submarine power transmission: For long-distance cable connections from a certain point (breakeven point in the order of 40-150 km), depending on the voltage level, HVDC cables are a more economical solution [10]. Additionally, submarine HVDC cables can be used for embedded HVDC as well as for interconnectors between asynchronous AC grids.

Long distance bulk power delivery: Similarly, for overhead lines, from a certain distance, a HVDC link is a more economical solution. In the literature, break-even distances on the order of 500-800 km are

found for overhead lines. HVDC links also perform well in long distance bulk power delivery, while in AC systems the reactive power flow limits the transmission distance and consequently are more costly [2], [10]. However, break-even distances are highly project-dependent.

**Embedded HVDC links:** Links operating along the AC power system for power transfer and area control: a good example of an embedded HVDC link is the Western HVDC link connecting Scotland to England/Wales.

**Ancillary services:** HVDC links can provide ancillary services; a typical example is the France-England Interconnector (IFA).

### III. RESEARCH MOTIVATION

In recent years, electrical systems for distributed generation have experienced increased expansion and importance owing to the increase in the integration of different renewable energy sources, such as photovoltaics and wind energy. As a consequence, a multidirectional energy flow is present in the point of common coupling (PCC), which is simultaneously shared by loads and generators. Voltage-source converter high-voltage direct current (VSC–HVDC) systems allow us to exploit the feature of a multidirectional power flow, as they can be used to interconnect several AC grids by means of DC networks [1].

Since HVDC systems offer some superior advantages to those of high-voltage alternating current (HVAC) schemes—such as the asynchronous connection of two or more independent AC networks, the lack of reactive power in the DC link, lower power losses [2]—they can contribute to provide a more reliable power network and to the development of smart grids [3,4].

From the first commercial HVDC system, i.e., the HVDC Gotland [5], to the present day, power electronics has undergone great advances. Several commercial HVDC systems can be found involving various technologies, such as HVDCs based on current-source converters (CSC), in addition to the

current VSC–HVDCs. The main different converter technologies have been explained in [6].

In accordance with [7,8], VSC–HVDC systems exhibit some advantages with regard to CSC–HVDCs, such as their four-quadrant operation, their use in the connection to both strong and weak grids, high dynamic performance and multi terminal possibility, and greater controllability [9]. Furthermore, multilevel topologies for VSC can be used in HVDCs in order to synthesize an output voltage with a low harmonic distortion. The most well-known multilevel configurations are the neutral-point clamped (NPC) converter [10], the flying-capacitor (FC) converter [11], and the modular multilevel converter (MMC) [12].

Among all the flexible transmission systems (FTS), HVDCs are the devices that offer the broadest range of functionalities, such as voltage control, active and reactive power control, frequency control, and the interconnection of AC systems [7]. Besides, HVDCs also feature some power quality (PQ) functionalities in order to ameliorate the PQ of the AC grids to which they are connected [13].

#### Vsc–Hvdc Systems

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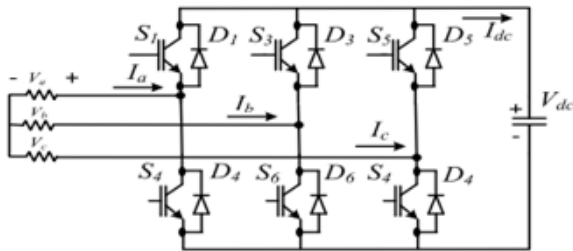


Fig.1. VSC Schematic Diagram [6].

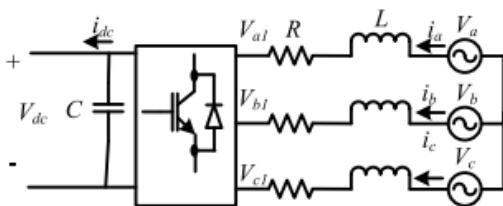


Fig.2. The equivalent circuit of a VSC connected with AC sources [2].

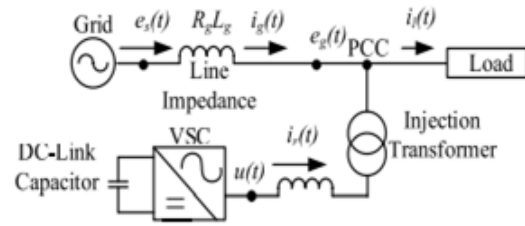


Fig.3. Single line diagram of shunt-connected VSC [9].

In series or parallel in a high power converter. The equivalent circuit of VSC converter connected to a three-phase AC source is shown in Fig. 3. The relationship of voltage and current between the converter and AC source is expressed in (1) [2].

### Proposed Differential Protection Algorithm Artificial Neural Network

The ANN is defined as one of the artificial intelligent methods which are widely used in modelling and pattern classification problems. The ANN consists of at least three layers; input, hidden and output layers. The complexity of the classification problem controls the number of hidden layers. It a highly connected group of neurons or preprocessors which resembles the human brain. They are connected with interconnects analogous to the biological synapse. Specifications of the connections' weights to implement the required operation should be represented as the network's software. The output and input layers have several neurons depends on the number of outputs and inputs of the problem. While the training patterns are used to calculate the hidden layers' neurons. So, the data patterns of input-output sets are utilized to train, validate, and test the ANNs [8].

The proposed algorithm for the protection of the VSC–HVDC system is built on combined wavelet and ANN. The wavelet decomposes the current signals at each end of the HVDC line into a low and high frequency component which called approximate coefficient and details coefficient respectively. Details coefficient of the DWT is utilized in Harmonic detection. After detecting the Harmonic, a decision

of Harmonic type of a HVDC line is executed by the ANN.

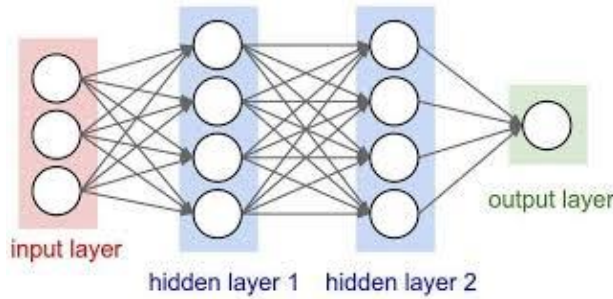


Fig.4. ANN layers.

The DC current signals are acquired by a sampling rate of 4kHz at both substations and four data windows (Ip12, Ip21, In12 and In21) with 20 samples data are applied as inputs to the proposed ANN. Those signals form the input vector to ANN.

**ANN output:**

ANN Harmonic detector: ANN output depends on the input vector. For a pre-fault conditions, the output of the ANN is equal to 0 while for post-fault conditions, the output of the ANN is equal to one. ANN Harmonic classifier: The Harmonic classifier is designed to obtain the Harmonic type in the HVDC systems. The Harmonic classifier is activated after the ANN Harmonic detector identify the Harmonic. The proposed ANN Harmonic classifier has five outputs to detect the Harmonic phase as: negative pole Harmonic, positive pole Harmonic, ground Harmonic, rectifier side Harmonic and inverter side Harmonic.

**ANN construction:**

The proposed ANN in Fig. 4 detects the Harmonics to identify if the input vectors belong to pre-fault conditions or post-fault conditions. The ANN used is a multi-layer feedforward neural networks (MFFNN) architecture with activation function of hyperbolic tangent which used in hidden layers. This function is appropriate for patterns classifications [2], whilst in the output layer a linear activation function is used. A moving window of length 5ms is used to catch the average value of each of the dc current signals by using 4kHz sample rate. The input layer of the proposed Harmonic detection ANN has 80 neurons

of the mean current's values captured from both DC line terminals from both positive and negative poles. There are two hidden layers; the first one consists of 26 neurons and the second one consists of 16 neurons as illustrated in Fig. 4. The output neuron relevant to Harmonic detection ANN is trained using backpropagation algorithm, to vary the output from zero to one to identify the detection of Harmonic. Harmonic classification ANN has the same inputs as the Harmonic detector. While the first and second hidden layers have 25 and 18 neurons respectively, as illustrated in Fig. 5. The output neuron relevant to Harmonic classification ANN is trained using back-propagation algorithm, to vary the outputs from zero to one to identify the type of the Harmonics.

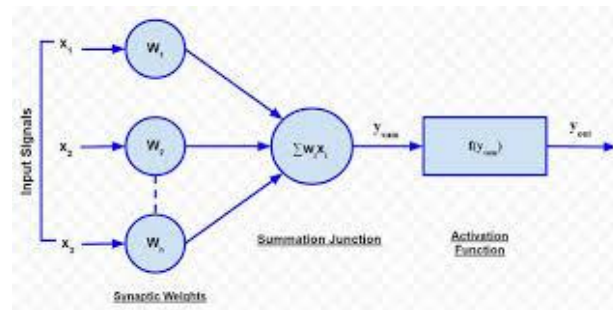


Fig.5. Propagation algorithm.

**Training process**

To train the proposed ANN a full range of normal and Harmonic operational conditions are taken into consideration. The pre-fault training patterns are obtained for a duration of 10ms with 5ms data window. While the training patterns of the normal operation is recorded for 20ms with 5ms data window. The training patterns are established from 66 cases based on numerous normal and Harmonic operating conditions of HVDC system. Each case of operating condition consists of input vectors of 22 pre-fault and 63 post-fault which result in 5412 input vectors. The input vectors of the pre- and post-fault do not get together for the training patterns. Thus, the training patterns are applied for training the proposed ANN Harmonic detector to result in an output equal zero for input related to the normal conditions and equal 1 for input vector related to the post-fault conditions. The training patterns are obtained by simulating the HVDC system according to different parameters. Therefore, all possible combinations do not present in the training set

except a sample of the 66 training cases are chosen to represent the problem boundaries. The proposed ANN is implemented, trained, and tested using MATLAB software.

### Result and Simulation

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 controller.

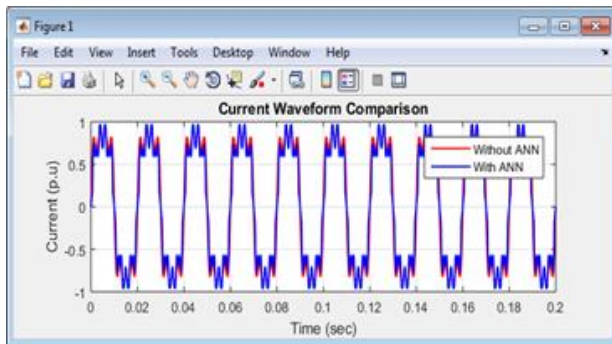


Fig.6.Current Vs Time.

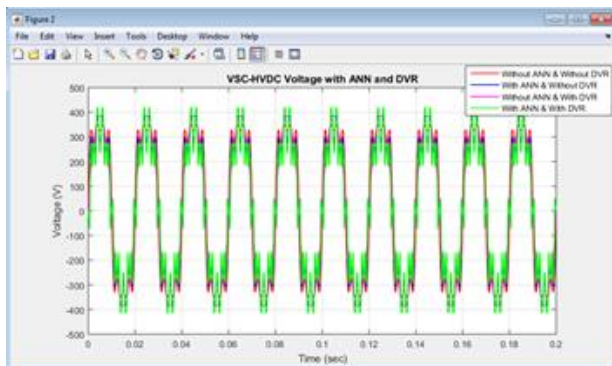


Fig.7. With ANN and Without ANN and DVR impact.

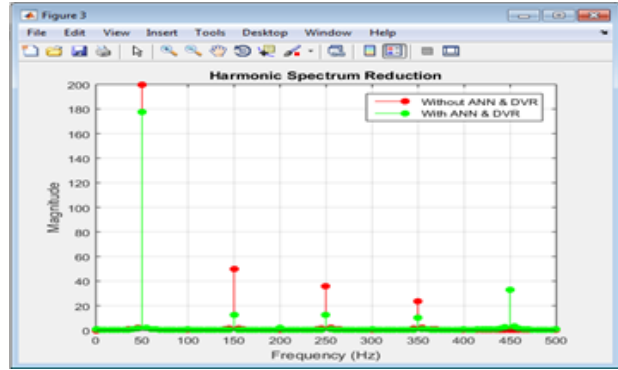


Fig.8. Magnitude and Frequency Spectrum.

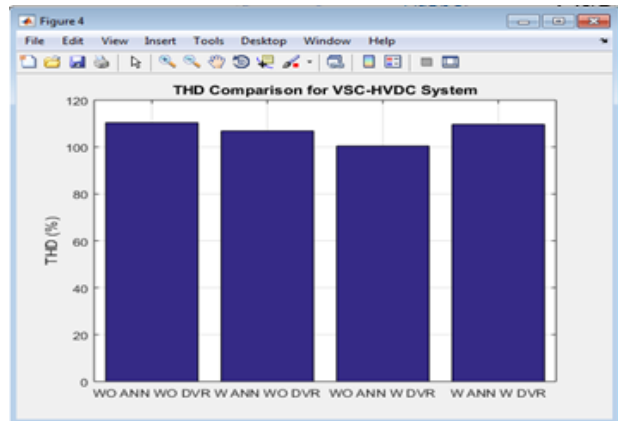


Fig.9.THd Variation.

## IV. CONCLUSIONS

DVR has proved to be a useful and well-performing device to improve power quality. The structure and the operation of the DVR were explained. This paper proved the %THD of ANN controller is less when compared to PI controller. This paper presented the ANN application to DVR for improved performance in mitigating voltage sag and swell compared to the conventional controller. The SRF theory was used for the estimation of reference DVR voltages. The simulation of the proposed system with sensitive load is carried out using MATLAB software. DVR performance has been shown by the simulation results during voltage disturbances. The proposed method was compared with the popular controller and proved to be the best option for restoring system voltage while reducing THD in the greater part.

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