International Journal of Emerging Technology in Computer Science & Electronics (IJETCSE)
ISSN: 0976-1353 Volume 24 Issue 8 – MAY 2017.

CFII IMPROVEMENT AND FAULT PROTECTION IN BIPOLAR HVDC TRANSMISSION LINES

S.VIJAYAKUMAR [#1] and Prof.L.P.VETTRIVELAN [*2]

[#] *Final year, M.E, Power systems Engineering, P.S.V College of Engineering and Technology,*
Krishnagiri (D.T) -India
[*] *Assistant Professor, Electrical and Electronics Engineering, P.S.V College of Engineering and Technology,*
Krishnagiri (D.T) -India

***Abstract*— A general platform is introduced to study the dynamics of power systems with high voltage dc (HVDC) transmission links. Small-signal stability, voltage stability, and interaction phenomena of power systems with both line-commutated-converter HVDC (LCC-HVDC) and voltage-source-converter HVDC (VSC-HVDC) are addressed using the proposed platform. In this platform, the entire power system is modelled as a multivariable feedback control system (FCS) which consists of three interconnected blocks. The contents as well as the inputs and outputs of the blocks are selected such that the conventional analysis tools for power system stability are applicable, both in the time and frequency domains. In the FCS model, the relationships between different instabilities are clear, and participant agents of each instability can be determined. The model is developed in a modular and hybrid style, to make it feasible for a large power system. The proposed model is validated using MATLAB simulation using a data mining method of ICA (Independent component analysis). CFII improvement in HVDC fault lines is realized additionally with the help of an embedded controller based on ATMEGA 328 series board. The designed system finds the fault and improves the CFII values. If the threshold is reached, then load protection is performed through the improved CFII. It is shown that any small additional improvement in the CFII would improve the final AC output. A conventional load of 230V and 20W have been installed and verified.**

***Index Terms*— LCC-HVDC, FCS, ICA, CFII.**

I. INTRODUCTION

A high-voltage, direct current (HVDC) electric power transmission system (also called a power super highway or an electrical super highway) uses direct current for the bulk transmission of electrical power, in contrast with the more common alternating current (AC) systems. For long-distance transmission, HVDC systems may be less expensive and suffer lower electrical losses. For underwater power cables, HVDC avoids the heavy currents required to charge and discharge the cable capacitance each cycle. For shorter distances, the higher cost of DC conversion equipment compared to an AC system may still be justified, due to other benefits of direct current links. HVDC allows power transmission between unsynchronized AC transmission systems. Since the power flow through an HVDC link can be controlled independently of the phase angle between source and load, it can stabilize a network against disturbances due to rapid changes in power. HVDC also allows transfer of power between grid systems running at different frequencies, such as 50 Hz and 60 Hz. This improves the stability and economy of each grid, by allowing exchange of power between incompatible networks. The modern form of HVDC transmission uses technology developed extensively in the 1930s in Sweden (ASEA) and in Germany. Early commercial installations included one in the Soviet Union in 1951 between Moscow and Kashira, and a 100 kV, 20 MW system between Gotland and mainland Sweden in 1954. The longest HVDC link in the world is the Rio Madeira link in Brazil, which consists of two bipoles of ±600 kV, 3150 MW each, and connecting Porto Velho in the state of Rondônia to the São Paulo area. The length of the DC line is 2,375 km (1,476 mi)

II. HV TRANSMISSION

High voltage is used for electric power transmission to reduce the energy lost in the resistance of the wires. For a given quantity of power transmitted, doubling the voltage will deliver the same power at only half the current. Since the power lost as heat in the wires is proportional to the square of the current for a given conductor size, but does not depend on the voltage, doubling the voltage reduces the line losses per unit of electrical power delivered by a factor of 4. While power lost in transmission can also be reduced by increasing the conductor size, larger conductors are heavier and more expensive. High voltage cannot readily be used for lighting or motors, so transmission-level voltages must be reduced for end-use equipment. Transformers are used to change the voltage levels in alternating current (AC) transmission circuits. Because transformers made voltage changes practical, and AC generators were more efficient than those using DC, AC became dominant after the introduction of practical systems of distribution in Europe in 1891 and the conclusion in 1892 of the War of Currents, a competition being fought on many fronts in the US between the DC system of Thomas Edison and the AC system of George Westinghouse. Practical conversion of power between AC and DC became possible with the development of power electronics devices such as mercury-arc valves and, starting in the 1970s, semiconductor devices as thyristors, integrated gate-commutated thyristors (IGCTs), MOS-controlled thyristors (MCTs) and insulated-gate bipolar transistors (IGBT).

A. *Capacitor-Commutated converters (CCC).*

Line-commutated converters have some limitations in their use for HVDC systems. This results from requiring the AC circuit to turn off the thyristor current and the need for a short period of 'reverse' voltage to effect the turn-off (turn-off time). An attempt to address these limitations is the Capacitor-Commutated Converter (CCC) which has been used in a small number of HVDC systems. The CCC differs from a conventional HVDC system in that it has series capacitors inserted into the AC line connections, either on the primary or secondary side of the converter transformer. The series capacitors partially offset the commutating inductance of the converter and help to reduce fault currents. This also allows a smaller extinction angle to be used with a converter/inverter, reducing the need for reactive power support. However, CCC has remained only a niche application because of the advent of voltage-source converters (VSC) which completely eliminate the need for an extinction (turn-off) time.

B. *Voltage-source converters (VSC)*

Widely used in motor drives since the 1980s, voltage-source converters started to appear in HVDC in 1997 with the experimental Hellsjön–Grängesberg project in Sweden. By the end of 2011, this technology had captured a significant proportion of the HVDC market. The development of higher rated insulated-gate bipolar transistors (IGBTs), gate turn-off thyristors (GTOs) and integrated gate-commutated thyristors (IGCTs), has made smaller HVDC systems economical. The manufacturer ABB Group calls this concept HVDC Light, while Siemens calls a similar concept HVDC PLUS (Power Link Universal System) and Alstom call their product based upon this technology HVDC MaxSine. They have extended the use of HVDC down to blocks as small as a few tens of megawatts and lines as short as a few score kilometres of overhead line. There are several different variants of VSC technology: most installations built until 2012 use pulse width modulation in a circuit that is effectively an ultra-high-voltage motor drive. Current installations, including HVDC PLUS and HVDC MaxSine, are based on variants of a converter called a Modular Multi-Level Converter (MMC). Multilevel converters have the advantage that they allow harmonic filtering equipment to be reduced or eliminated altogether. By way of comparison, AC harmonic filters of typical line-commutated converter stations cover nearly half of the converter station area.With time, voltage-source converter systems will probably replace all installed simple thyristor-based systems, including the highest DC power transmission applications

C. *Advantages of HVDC over AC transmission*

A long distance point to point HVDC transmission scheme generally has lower overall investment cost and lower losses than an equivalent AC transmission scheme. HVDC conversion equipment at the terminal stations is costly, but the total DC transmission line costs over long distances are lower than AC line of the same distance. HVDC requires less conductor per unit distance than an AC line, as there is no need to support three phases and there is no skin effect. Depending on voltage level and construction details, HVDC transmission losses are quoted as about 3.5% per 1,000 km, which are 30 – 40% less than with AC lines, at the same voltage levels. This is because direct current transfers only active power and thus causes lower losses than alternating current, which transfers both active and reactive power. HVDC transmission may also be selected for other technical benefits. HVDC can transfer power between separate AC networks. HVDC power flow between separate AC systems can be automatically controlled to support either network during transient conditions, but without the risk that a major power system collapse in one network will lead to a collapse in the second. HVDC improves on system controllability, with at least one HVDC link embedded in an AC grid—in the deregulated environment, the controllability feature is particularly useful where control of energy trading is needed. DC grids with multiple voltage-source converters (VSCs) are one of the technical solutions for pooling offshore wind energy and transmitting it to load centers located far away onshore.

D. *Cable systems.*

Long undersea / underground high-voltage cables have a high electrical capacitance compared with overhead transmission lines, since the live conductors within the cable are surrounded by a relatively thin layer of insulation (the dielectric), and a metal sheath. The geometry is that of a long co-axial capacitor. The total capacitance increases with the length of the cable. This capacitance is in a parallel circuit with the load. Where alternating current is used for cable transmission, additional current must flow in the cable to charge this cable capacitance. This extra current flow causes added energy loss via dissipation of heat in the conductors of the cable, raising its temperature. Additional energy losses also occur as a result of dielectric losses in the cable insulation. However, if direct current is used, the cable capacitance is charged only when the cable is first energized or if the voltage level changes; there is no additional current required. For a sufficiently long AC cable, the entire current-carrying ability of the conductor would be needed to supply the charging current alone. This cable capacitance issue limits the length and power carrying ability of AC powered cables. DC powered cables are limited only by their temperature rise and Ohm's Law. Although some leakage current flows through the dielectric insulator, this is small compared to the cable's rated current.

E. *Overhead line systems*

The capacitive effect of long underground or undersea cables in AC transmission applications also applies to AC overhead lines, although to a much lesser extent. Nevertheless, for a long AC overhead transmission line, the current flowing just to charge the line capacitance can be significant, and this reduces the capability of the line to carry useful current to the load at the remote end. Another factor that reduces the useful current carrying ability of AC lines is the skin effect, which causes a non-uniform distribution of current over the cross-sectional area of the conductor. Transmission line conductors operating with direct current do not suffer from either of these constraints. Therefore, for the same conductor losses (or heating effect), a given conductor can carry more current to the load when operating with HVDC than AC. Finally, depending upon the environmental conditions and the performance of overhead line insulation operating with HVDC, it may be possible for a given transmission line to operate with a constant HVDC voltage that is approximately the same as the peak AC voltage for which it is designed and insulated. The power delivered in an AC system is defined by the root mean square (RMS) of an AC voltage, but RMS is only about 71% of the peak voltage. Therefore, if the HVDC line can operate continuously with an HVDC voltage that is the same as the peak voltage of the AC equivalent line, then for a given current (where HVDC current is the same as the RMS current in the AC line), the power transmission capability when operating with HVDC is approximately 40% higher than the capability when operating with AC.

F. Asynchronous connections

Because HVDC allows power transmission between unsynchronized AC distribution systems, it can help increase system stability, by preventing cascading failures from propagating from one part of a wider power transmission grid to another. Changes in load that would cause portions of an AC network to become unsynchronized and to separate, would not similarly affect a DC link, and the power flow through the DC link would tend to stabilize the AC network. The magnitude and direction of power flow through a DC link can be directly controlled, and changed as needed to support the AC networks at either end of the DC link. This has caused many power system operators to contemplate wider use of HVDC technology for its stability benefits alone.

III. INDEPENDENT COMPONENTS ANALYSIS

ICA finds the independent components (also called factors, latent variables or sources) by maximizing the statistical independence of the estimated components. We may choose one of many ways to define a proxy for independence, and this choice governs the form of the ICA algorithm. The two broadest definitions of independence for ICA are

- Minimization of mutual information
- Maximization of non-Gaussianity

The Minimization-of-Mutual information (MMI) family of ICA algorithms uses measures like Kullback-Leibler Divergence and maximum entropy. The non-Gaussianity family of ICA algorithms, motivated by the central limit theorem, uses kurtosis and negentropy. Typical algorithms for ICA use centering (subtract the mean to create a zero mean signal), whitening (usually with the eigenvalue decomposition), and dimensionality reduction as preprocessing steps in order to simplify and reduce the complexity of the problem for the actual iterative algorithm. Whitening and dimension reduction can be achieved with principal component analysis or singular value decomposition. Whitening ensures that all dimensions are treated equally a priori before the algorithm is run. Well-known algorithms for ICA include infomax, FastICA, JADE, and kernel-independent component analysis, among others. In general, ICA cannot identify the actual number of source signals, a uniquely correct ordering of the source signals, nor the proper scaling (including sign) of the source signals. ICA is important to blind signal separation and has many practical applications. It is closely related to (or even a special case of) the search for a factorial code of the data, i.e., a new vector-valued representation of each data vector such that it gets uniquely encoded by the resulting code vector (loss-free coding), but the code components are statistically independent. A common problem in data processing is that large amounts of data are expensive to *transmit*, *store* or *process*. For transmitting we need high bandwidth, for storing large storage space and for processing we need complex computer systems to reduce the long processing time. To reduce the amount of data, would mean a reduction in expenses. But simply throwing away part of the data would result in a loss of information, which could be important. In so called *random data*, like for example data from classs, sounds or other samples, there is however a difference in how important each part of data is to the information which is stored in the data. By leaving out the part of data which is the least valuable to the information, we reach a reduction of the amount of data.

Independent Components Analysis (ICA) is used to compress data in such a way that the least information is lost. It does so by truncating data and thereby leaving out the data which is of the least importance to the information stored in the data. This ICA process is called *dimensionality reduction*, because a vector $\overline{x}$ which contains the original data and is N-dimensional is reduced to a compressed vector $\overline{c}$ which is M-dimensional, where M<N. The question that is answered by ICA is: how can we map vector $\overline{x}$ into a vector $\overline{c}$ with a smaller dimension, but where the information contained in $\overline{x}$ is more or less equal to the information stored in $\overline{c}$?

A. CONCEPT OF ICA

Independent Component Analysis (ICA) has been proven to be an efficient method in pattern recognition and class analysis, Given a random vector $\overline{x}$ of dimension N and its correlation matrix $\overline{\overline{R}}$ we can reduce its dimension to M (with M<N) by Independent Components Analysis in six steps:

1. Find the eigenvectors $\overline{\overline{Q}}$ and eigenvalues λ_i of correlation matrix $\overline{\overline{R}}$:

$$\overline{\overline{R}}\,\overline{q}_i = \lambda_i \overline{q}_i$$

2. Arrange the eigenvalues in decreasing order:

$$\lambda_1 > \lambda_2 > .. > \lambda_M > .. > \lambda_N$$

3. Pick up the eigenvectors which belong to the first M largest eigenvalues.
4. Calculate compressed vector $\overline{c}$ by $c_i = \overline{x}^T \overline{q}_i$ for i = 1, .., M
5. Use vector $\overline{c}$ for storage, transmission, process, etc.
6. Decode the resulting vector $\overline{c}'$ into N-dimensional vector $\tilde{\overline{x}}'$ using the eigenvector matrix $\overline{\overline{Q}}$.

$$\tilde{\bar{x}}' = \sum_{i=1}^{M} c_i \bar{q}_i$$

B. Generating a correlation matrix

To use Independent Components Analysis we need to have a correlation matrix, which defines the similarity between different input vectors. To obtain a correlation matrix $\bar{\bar{R}}$, we construct one by means of observations of different input vectors. We examine for example K different class for constructing matrix $\bar{\bar{R}}$ for aICA of class. We note $\bar{x}^{(k)}$ as being the k-th observed class.

We use the following empirical approximation of $\bar{\bar{R}}$:

$$\tilde{R}_{ij} = \frac{1}{K}\sum_{k=1}^{K} x_i^{(k)} x_j^{(k)}$$

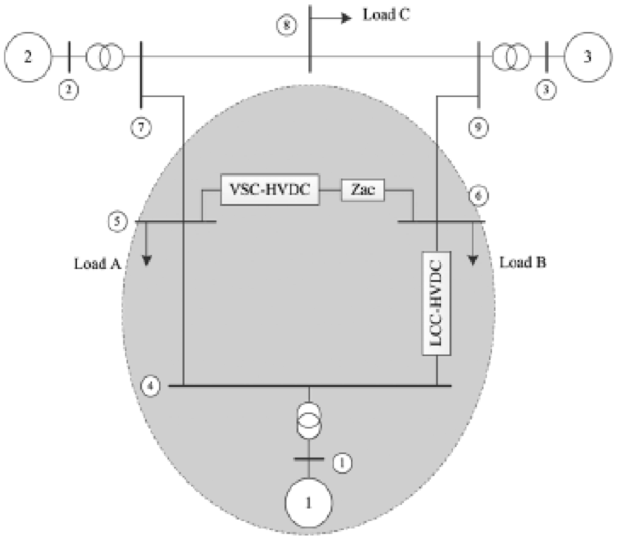
The more observations are made, the better the approximation $\tilde{\bar{\bar{R}}}$ of $\bar{\bar{R}}$ gets. Instead of matrix $\bar{\bar{R}}$ we use matrix $\tilde{\bar{\bar{R}}}$ in the ICA calculations.

A) Kernel method

To determine the eigenvectors of correlation matrix $\bar{\bar{R}}$, we have to construct the matrix $\bar{\bar{R}}$ by calculating the outer product of vector $\bar{x}$. In most applications of ICA, this vector $\bar{x}$ is very large, as it represents the data which is to be compressed. The complexity of the calculations are high, namely $O(N^3)$. There is a way in which we can reduce this complexity to $O(K^3)$, where K is much smaller than N, when we use the limited number of observations of vectors $\bar{x}$ to construct the needed eigenvectors for ICA.

IV. OPERATING PRINCIPLE

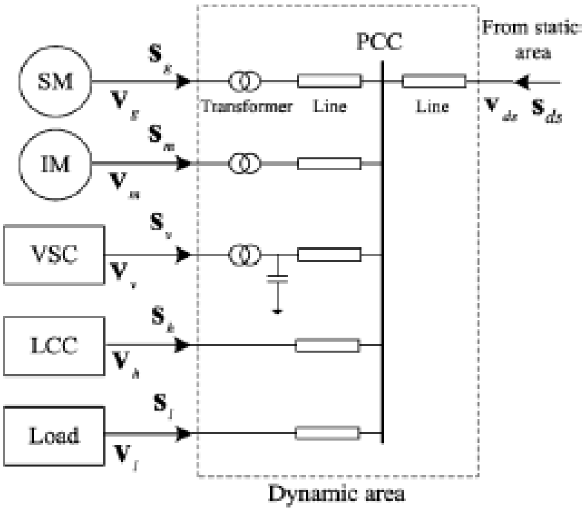
The scenario of power system under HVDC is as shown in the following figure.



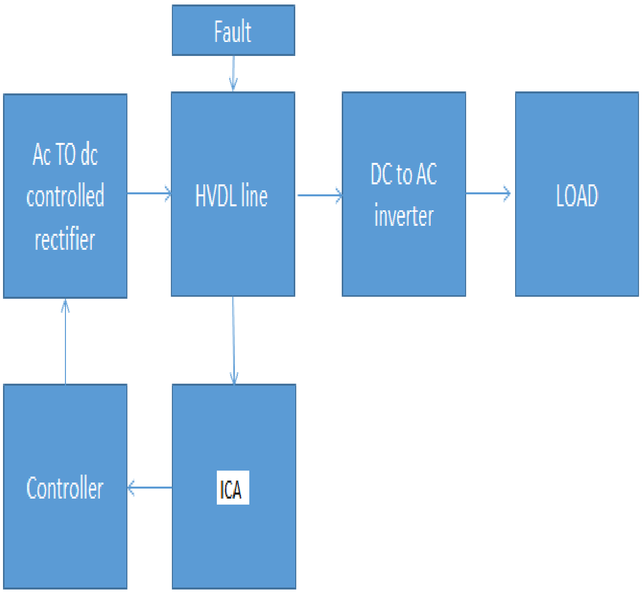
In the future power system, the increasing number of high voltagedc (HVDC) transmission links, imposes the serious challenges on power system control and stability analysis. While some of HVDC systems offer better controllability and improvement of global power-system stability, there is also an increased risk for local instabilities which can either start as parasitic small signal oscillations [1], [2], or concurrent commutation failure of converters consequently impair voltage quality or cause highover-voltage at the converter ac buses [3]. To analyze the nature and causes of these instabilities, appropriate analytical models of power systems and HVDC links are required. The electro-magnetic transient programs (EMTPs), as time-domain simulation tools, demonstrate instabilities; however, they do not provide the analytical insight (e.g., information about participants in instability or stability margins) needed for optimal system design [4]. In addition, these programs have practical simulation restrictions on the extent of the ac system [5]. The conventional transient stability programs (TSPs), which use phasor modeling techniques [6], do not have these aforementioned problems, but they cannot directly represent the faster transients characterizing the HVDC systems [6]. Some authors have proposed considering EMTP based models of HVDC links into TSPs [5]–[7]; in this case, the problem of analytical investigation of instabilities still exists.

However, when the number of HVDC converters (and/or other power-electronic devices) is increased, the high-frequency interaction between different devices will be so complicated [13] that local analysis may not result in a reliable conclusion. Moreover, it has been declared in [14] that the HVDC controller design might suffer from lack of an accurate power system model if only the dynamics of a small portion of it is regarded. Onthe one hand, considering dynamics of all power components and ac system results in a huge number of state variables, of which most of are inessential. On the other hand, all of the electrical network dynamics cannot be neglected while analyzing the interactions among HVDC converters [2], [14]–[16] (otherwise, the TSPs could have been used for the same purpose). In a hybrid model of power system has been proposed to overcome this problem; in fact, the areas of power system which consist of HVDC converters are modeled including ac network dynamics, and the remaining parts are modeled using the power frequency admittance matrix. Although this model reflects the nature of oscillations in power systems, but still it is not the best tool when the proportional gain of a controller causes instability.

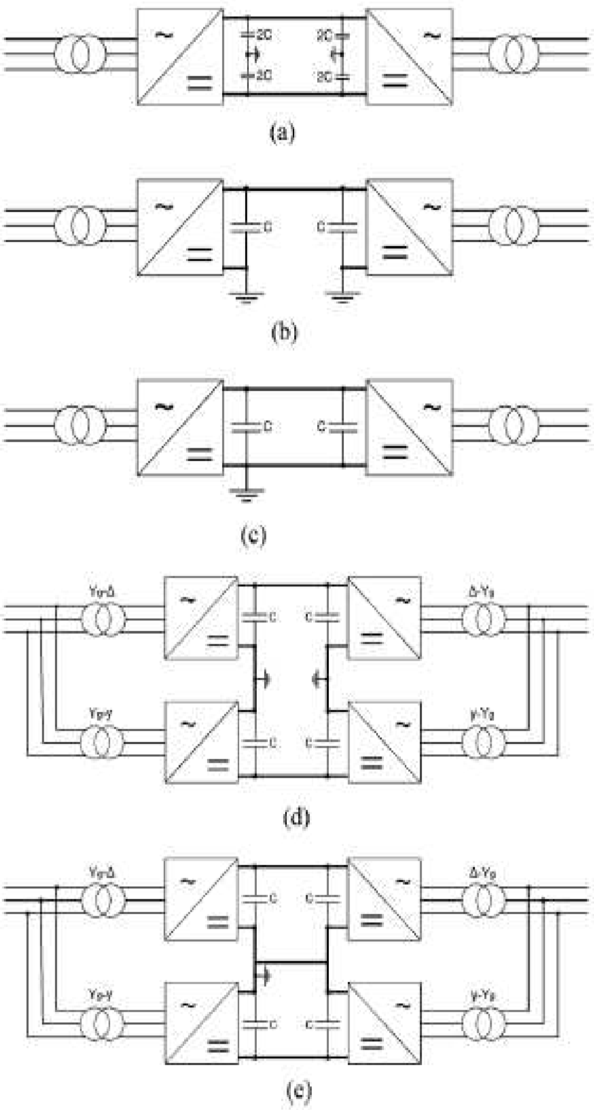
Also, the small-signal stability cannot be analyzed in the frequency domain to obtain gain and phase margins of stability, which are crucial in controller design. Moreover, in [14], the voltage-source converter-based HVDC (VSC-HVDC), which is more promising device in future power systems, has not been considered. In [13], [16]–[20], a new concept, called Jacobian Transfer Matrix (JTM), has been used to model a VSC-connected ac grid to introduce a new control system for converter. The JTM not only can analyze the stability issues but it also regards the ac network model in a feedback loop which is ideal for VSC controller design. The stability analysis by JTM is based on monitoring the zeros of network transfer function [16], therefore, it is limited to a small power system. Moreover, the LCC-HVDC model has not been included in JTM-based model. This paper benefits from advantages of JTM [13], [16]–[20] and hybrid ac system model [14] to propose a unified model of a power system with both types of HVDC links to analyze not only small-signal stability and high-frequency interactions in any size of power systems, but also voltage stability and steady state interactions [3]. The models of HVDC converters, dc-links, loads, and electrical parts of machines are included in block , and the ac network model is considered in block . The combination of blocks and , in the dashed rectangle in Fig. 1, is a hybrid form of a modified JTM. Indeed, to make the FCS model applicable for any size of power system, the ac network is presented with a hybrid model in the same way as done in [14]. By eigenvalue analysis of the closed-loop FCS model and by analyzing the frequency response of FCS open-loop transfer functions, the small-signal and high-frequency interactions can be studied. The voltage stability and steady-state interactions are investigated by modal and/or nodal analysis of the block model in quasi-static form which resembles the load-flow Jacobian matrix that can be used for the same purpose [3].



Statistical models are useful but cannot replace detailed simulations to understand particular cascading mechanisms in depth. There are also topological models which have been applied to the identification of vulnerable/critical elements, however, without detailed power grid information, the results that they yield differ greatly and could result in misleading conclusions about the grid vulnerability. Some dynamic models and numerical techniques study the mid-/long-term dynamics of power system behavior and show that mid-/long-term stability is an important part of cascading outage mechanisms. However, concurrent modeling of power system dynamics and discrete protection events-such as line tripping by over-current, distance and temperature relays, under voltage, and under frequency load shedding is challenging and not considered in most existing models. In existing works they describe an initial approach using a system of differential-algebraic equations with an additional set of discrete equations to dynamically model cascading failures. The associated power flows are represented using nonlinear power flow equations. Load voltage responses are explicitly represented, and discrete changes (e.g., components failures or load shedding) are described by a set of equations that indicate the proximity to thresholds that trigger discrete changes. Block diagram of overall proposed system is as follows,



The following different architecture of HVDC system has been considered in this work,



(a)

(b)

(c)

(d)

(e)

A. PARAMETERS

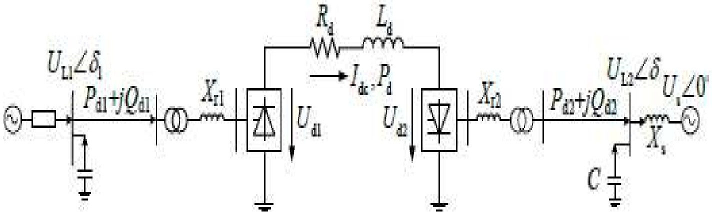
Monopole: In a common configuration, called monopole, one of the terminals of the rectifier is connected to earth ground. The other terminal, at a potential high above or below ground, is connected to a transmission line. The earthed terminal may be connected to the corresponding connection at the inverting station by means of a second conductor. **Monopole and earth return:** If no metallic conductor is installed, current flows in the earth and/or sea between two specially designed earth electrodes. This arrangement is a type of single wire earth return system. The electrodes are usually located some tens of kilometres from the stations and are connected to the stations via a medium-voltage electrode line. The design of the electrodes themselves depends on whether they are located on land, on the shore or at sea. For the mono polar configuration with earth return, the earth current flow is unidirectional, which means that the design of one of the electrodes (the cathode) can be relatively simple, although the design of anode electrode is quite complex. For long-distance transmission, earth return can be considerably cheaper than alternatives using a dedicated neutral conductor, but it can lead to problems such as: **Electrochemical corrosion of long buried metal objects such as pipelines,** Underwater earth-return electrodes in seawater may produce chlorine or otherwise affect water chemistry. An unbalanced current path may result in a net magnetic field, which can affect magnetic navigational compasses for ships passing over an underwater cable.

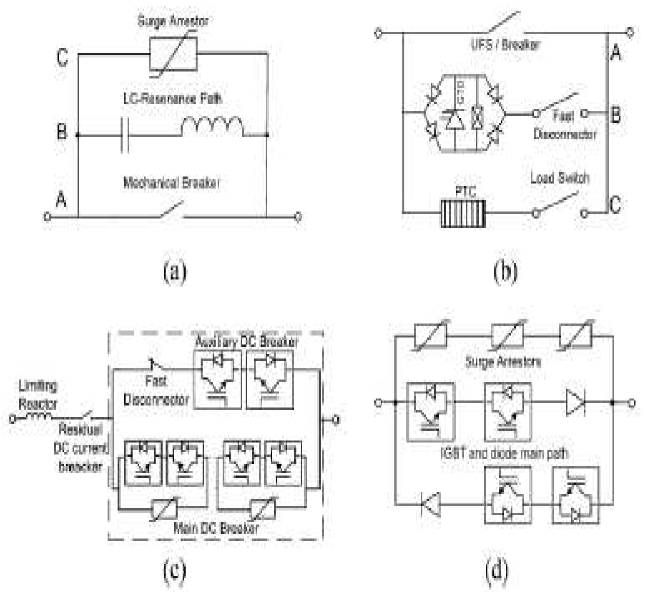
Monopole and metallic return: These effects can be eliminated with installation of a metallic return conductor between the two ends of the mono polar transmission line. Since one terminal of the converters is connected to earth, the return conductor need not be insulated for the full transmission voltage which makes it less costly than the high-voltage conductor. The decision of whether or not to use a metallic return conductor is based upon economic, technical and environmental factors. Modern monopolar systems for pure overhead lines carry typically 1.5 GW. If underground or underwater cables are used, the typical value is 600 MW. Most monopolar systems are designed for future bipolar expansion. Transmission line towers may be designed to carry two conductors, even if only one is used initially for the monopole transmission system. The second conductor is either unused, used as electrode line or connected in parallel with the other (as in case of Baltic Cable). **Symmetrical monopole:** An alternative is to use two high-voltage conductors, operating at ± half of the DC voltage, with only a single converter at each end. In this arrangement, known as the symmetrical monopole, the converters are earthed only via a high impedance and there is no earth current. The symmetrical monopole arrangement is uncommon with line-commutated converters (the NorNed interconnection being a rare example) but is very common with Voltage Sourced Converters when cables are used. **Bipolar:** In bipolar transmission a pair of conductors is used, each at a high potential with respect to ground, in opposite polarity. Since these conductors must be insulated for the full voltage, transmission line cost is higher than a monopole with a return conductor. However, there are a number of advantages to bipolar transmission which can make it an attractive option.

Under normal load, negligible earth-current flows, as in the case of monopolar transmission with a metallic earth-return. This reduces earth return loss and environmental effects. When a fault develops in a line, with earth return electrodes installed at each end of the line, approximately half the rated power can continue to flow using the earth as a return path, operating in monopolar mode. In very adverse terrain, the second conductor may be carried on an independent set of transmission towers, so that some power may continue to be transmitted even if one line is damaged. A bipolar system may also be installed with a metallic earth return conductor. Bipolar systems may carry as much as 4 GW at voltages of ±660 kV with a single converter per pole, as on the Ningdong–Shandong project in China. With a power rating of 2000 MW per twelve-pulse converter, the converters for that project were (as of 2010) the most powerful HVDC converters ever built. Even higher powers can be achieved by connecting two or more twelve-pulse converters in series in each pole, as is used in the ±800 kV Xiangjiaba–Shanghai project in China, which uses two twelve-pulse converter bridges in each pole, each rated at 400 kV DC and 1600 MW.

B. IMPLEMENTATION

Small-signal stability, voltage stability, and interaction phenomena of power systems with both line-commutated-converter HVDC (LCC-HVDC) and voltage-source-converter HVDC (VSC-HVDC) are addressed using the proposed platform. The voltage data is first fed into ICA to separate the valid voltage information based on windowing method and sequentially applied to a clustering algorithm (optional) whose results are used to control the stability of the HVDC based power systems. In this project a unified model of a power system with both types of HVDC transmission links (LCC- and VSC-HVDC) was proposed as a multi-variable feedback control system (FCS), which facilitated both the voltage and small-signal stabilities analyses. These models are usually used in local studies, where a small portion of power system including HVDC converter is modeled in detail and the rest of the power system is replaced by an equivalent simple circuit. Line commutated converter based high voltage direct current (LCC-HVDC) has been wildly applied in many areas, such as asynchronous ac grid connection, long distance bulk power transmission, etc.. However, if the short circuit ratio (SCR) of ac network is low, the LCC-HVDC system would have poor voltage regulation ability and be susceptible to commutation failures (CFs). The CFs issues can be alleviated by synchronous condenser (SC), static synchronous compensators (STATCOM) or Voltage source Converter based HVDC (VSC-HVDC), all of that can supply the dynamic reactive power for LCC-HVDC. However, more extra capital costs are required for additional apparatus to CFs mitigation.





We have used an inbuilt library based breaker, whose on and off resistances are set to ideal conditions.

V. SIMULATION

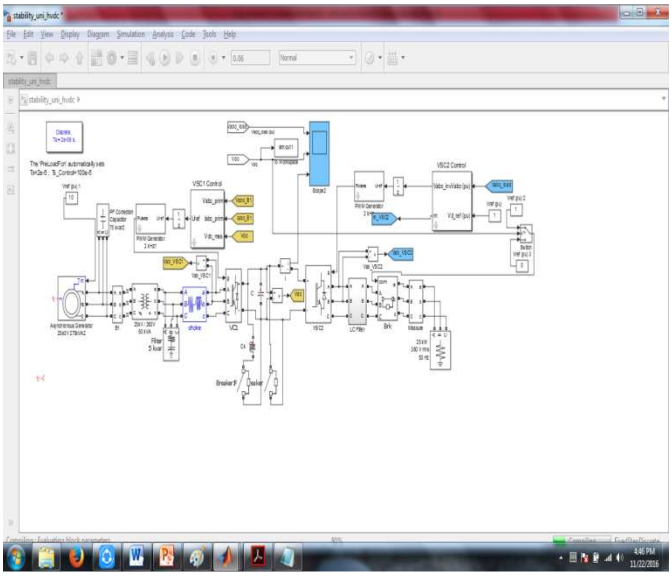


Fig. 5.1 Unipolar Mode

The model consists of a power system energised by a renewable wind energy source. The plant has been assumed to be a three phase voltage source energised by a wind source. The power generated is coupled to an isolation transformer and connected to RF choke to filter out the noise in electrical loads. Now the DC voltage is rectified using a controlled rectifier using ideal switches. The gate pulses are supplied from a control section, which takes DC voltage Vdc as feed back and the PWM frequency is set as 2KHz. The rectified DC is the filtered with a capacitor. This DC voltage is inverted and the same is filtered using LC filter and supplied to a final AC load. While inverter is designed, it takes a reference value and feed back vlaues of load current and load voltage. A fault is created in the DC bus section where the data is taken and moved to independent component analysis.

A. *OUTPUTS WITHOUT FEEDBACK*

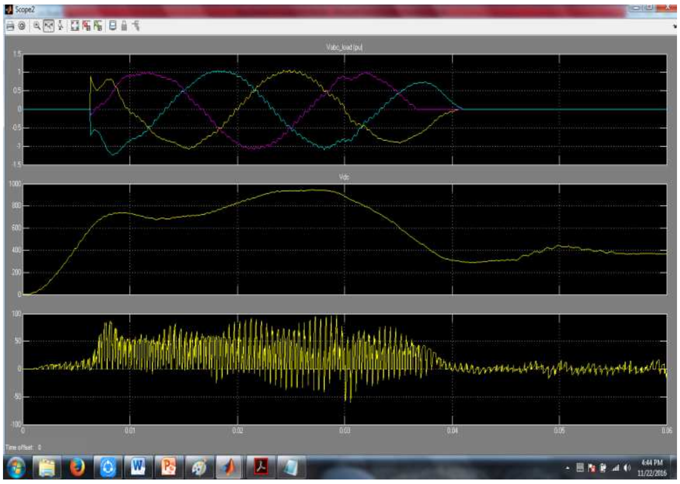


Fig.5.2 3 Phase AC and DC Bus Voltage

The diagram shows that the fault occurs at 0.04 s and where the bus voltage is reduced upto 400 volts.

X –axis - Time in seconds

Y – axis 1 – Three phase voltage

Y – axis 2 – DC bus voltage

Y – axis 3 – DC bus current

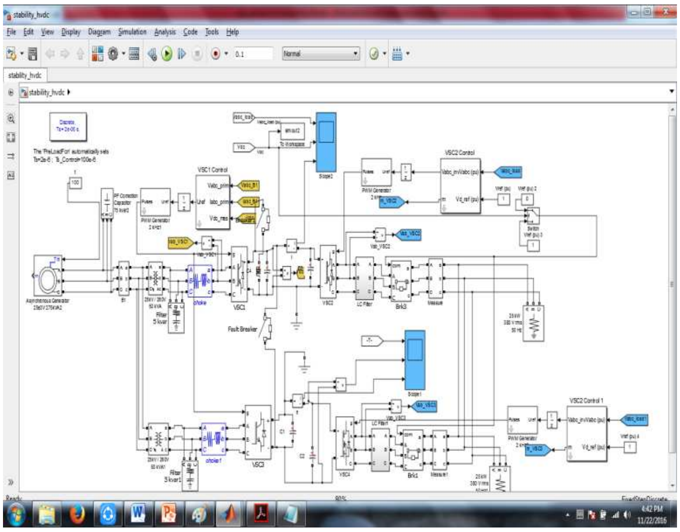


Fig.5.3 Bipolar Mode

The model consists of a power system energised by a renewable wind energy source. The plant has been assumed to be a three phase voltage source energised by a wind source. The power generated is coupled to an isolation transformer and connected to RF choke to filter out the noise in electrical loads. Now the DC voltage is divided into bipolar voltages using a common grounded capacitor sources. Hence two rectifiers are used in this stage.using ideal switches. The gate pulses are supplied from a control section, which takes DC voltage Vdc as feed back and the PWM frequency is set as 2KHz. The rectified DC is the filtered with a capacitor. This DC voltage is inverted and the same is filtered using LC filter and supplied to a final AC load. While inverter is designed, it takes a reference value and feed back vlaues of load current and load voltage. A fault is created in the DC bus section where the data is taken and moved to independent component analysis.

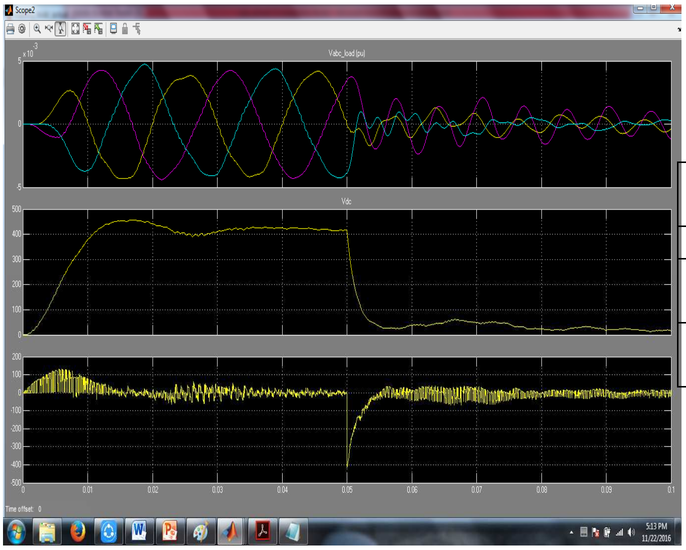


Fig.5.4 Before Stabilization

The diagram shows that the fault occurs at 0.04 s and where the bus voltage is reduced upto 100 volts. This is obtained without stabilization.

X –axis - Time in seconds
Y – axis 1 – Three phase voltage
Y – axis 2 – DC bus voltage
Y – axis 3 – DC bus current

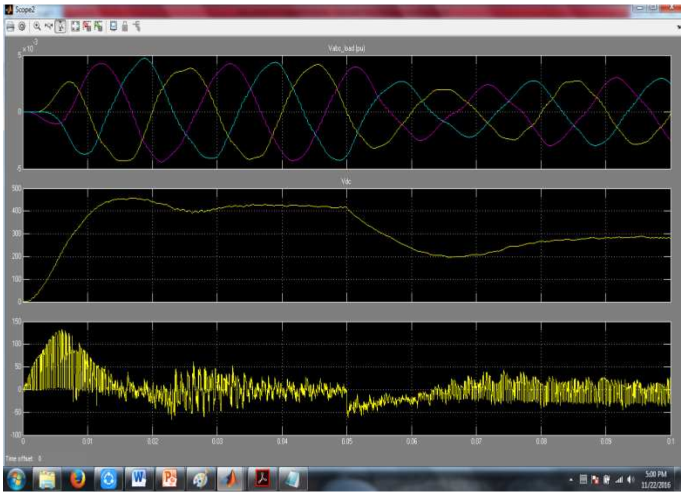


Fig. 5.5 After Stabilization

The diagram shows that the fault occurs at 0.04 s and where the bus voltage is reduced upto 300 volts only while improving the CFII.

X –axis - Time in seconds
Y – axis 1 – Three phase voltage
Y – axis 2 – DC bus voltage
Y – axis 3 – DC bus current

B. *CFII VALUES*

The CFII index is adopted here to evaluate the susceptibility of LCC converter to CFs and it is defined as in equation given below,

$$CFII = \frac{Critical\ Fault\ MVA}{P_d} \cdot 100\ (\%)$$

The CFII is determined by conducting a sequence of EMT simulations, each with an inductive fault applied to the converter bus. The *Critical Fault MVA* is the strength of the most severe fault that the tested system can survive without experiencing any CFs. P_d is the dc power of the converter. The larger CFII value represents stronger immunity of LCC inverter to Critical faults.

CFII in % (before stabilization) = 50/420 = 11.9%
CFII in % (After stabilization) = 280/420 = 66.6%

PARAMETERS	BEFORE STABILIZATION	AFTER STABILIZATION
CFII (%)	11.9	66.6
AC VOLTAGE (p.u)	$0.5X10^{-3}$	$2.5X10^{-3}$
DC BUS VOTLAGE (v)	50	280

VI. CONCLUSION & FUTURE WORK

In this project a unified model of a power system with both types of HVDC transmission links (LCC- and VSC-HVDC) was proposed as a multi-variable feedback control system (FCS), which facilitated both the voltage and small-signal stabilities analyses based on Independent component analysis. A methodology has been proposed to model a HVDC fault system and to mitigate the faults so as to improve the CFII values for both unipolar and bipolar converters. The proposed methodology consists of six steps ICA to identify the HVDC fault Among all analyzed topologies, the symmetric monopolar has the best fault response, especially in combination with at least 50-mH reactors. If the power to be transmitted in the dc network requires the use of bipolar topologies, the bipolar topology with metallic return, although it has higher capital installation costs, has superior performance with regard to dc faults than the one with ground return. In conclusion, a successful fault isolation in topologies with ground or metallic return requires solid-state breakers or Hybrid I breakers with reactors higher than 50 mH or 100 mH, respectively. Since inductors are bulky in nature, capacitance improvement is done in order to reduce the size of the system less. The value of CFII found in our proposed method is very compromising.

Bode plot or nyquist analysis could be done for FCS to determine constant 'k' value such that the roots of the characteristic equation always in the left hand side the complex plane. Chaotic based stability analysis is highly possible and it may be tried by future researchers. Presently the fault have been detected only at the commutator side and the DC capacitor faults. There could be a still more implementation to solve both DC and AC tolerant systems. The control algrithms can be programmed via an ASIC (application specific integrated circuit) to implement a hardware part of the same. Breakers connected to ethernet would be highly useful for online tracking and instaneous decisin making based on the faults occurred.

REFERENCES

[1] L. Harnefors, M. Bongiorno, and S. Lundberg, "Input-admittance calculation and shaping for controlled voltage-source converters," *IEEE Trans. Ind. Electron., vol. 54, no. 6, pp. 3323–3334, Dec. 2007.*

[2] C. Karawita and U. D. Annakkage, "Multi-infeed HVDC interaction studies using small-signal stability assessment," *IEEE Trans. Power Del., vol. 24, no. 2, pp. 910–918, Apr. 2009.*

[3] D. Lee and G. Andersson, "Analysis of voltage and power interactions in multi-infeed HVDC systems," *IEEE Trans. Power Del., vol. 28, no.* 2, pp. 816–824, Apr. 2013.

[4] S. Todd, A. R. Wood, and P. S. Bodger, “An s-domain model of an hvdc converter,” *IEEE Trans. PowerDel., vol. 12, no. 4, pp. 1723–1729, Oct.* 1997.

[5] J. Reeve and R. Adapa, “A new approach to dyanamic analysis of ac networks incorporating detailed modeling of dc systems. part i: Principles and implementation,” *IEEE Trans. Power Syst., vol. 3, no. 4, pp.* 2005–2011, Nov. 1988.

[6] M. Sultan, J. Reeve, and R. Adapa, “Combined transient and dynamic analysis of hvdc and facts systems,” *IEEE Trans. Power Syst., vol. 13,* no. 4, pp. 1271–1277, Nov. 1998.

[7] H. T. Su, K. W. Chan, and L. A. Snider, “Investigation of the use of electromagnetic transient models for transient stability simulation,” in *Proc. 6th IntConf, Advances in Power Syst. Control, Operation and Management, Hong Kong, 2003, pp. 787–792.*

[8] C. Osauskas and A. Wood, “Small-signal dynamic modeling of HVDC systems,” *IEEE Trans. Power Del., vol. 18, no. 1, pp. 220–225, Jan.* 2003.

[9] C. Osauskas, D. Hume, and A. Wood, “Small signal frequency domain model of an HVDC converter,” *Proc. Inst. Electr. Eng.—Gener.,Transm. Distrib., vol. 148, no. 6, pp. 220–225, Nov. 2001.*

[10] X. Yang and C. Chen, “Hvdc dynamic modelling for small signal analysis,” *Proc. Inst. Electr. Eng.—Gener.,Transm. Distrib., vol. 151, no.* 6, pp. 740–746, Nov. 2004.

[11] P. F. de Toledo, L. Ängquist, and H.-P.Nee, “Frequency domain model of an HVDC link with a line-commutated current-source converter.part i: Fixed overlap,” *IET Gener. Transm.Distrib., vol. 3, no. 8, pp.*757–770, Mar. 2009.

[12] P. F. de Toledo, L. Ängquist, and H.-P.Nee, “Frequency domain model of an HVDC link with a line-commutated current-source converter.part ii: Varying overlap,” *IET Gener. Transm.Distrib., vol. 3, no. 8,* pp. 771–782, Mar. 2009.

[13] L. Zhang, “Modeling and Control of VSC-HVDC Links Connected to Weak ac Systems,” Ph.D. dissertation, Dept. Electr.Energy Conv., Royal Inst. Technol., Stockholm, Sweden, 2010.

[14] C. Karawita and U. D. Annakkage, “A hybrid network model for small signal stability analysis of power systems,” *IEEE Trans. Power Syst.,* vol. 25, no. 1, pp. 443–451, Feb. 2010.

[15] D. Jovcic, N. Pahalawaththa, and M. Zavahir, “Analytical modeling of HVDC-HVAC systems,” *IEEE Trans. Power Del., vol. 14, no. 2, pp.* 506–511, April 1999.

[16] L. Zhang, H.-P. Nee, and L. Harnefors, “Analysis of stability limitations of a VSC-HVDC link using power-synchronization control,” *IEEE Trans. Power Syst., vol. 26, no. 1, pp. 1326–1337, Feb. 2011.*

[17] L. Zhang, L. Harnefors, and H.-P. Nee, “Power-synchronization control of grid-connected voltage-source converters,” *IEEE Trans. Power Syst., vol. 25, no. 2, pp. 809–820, May 2010.*

[18] L. Zhang, L. Harnefors, and H.-P. Nee, “Modeling and control of VSCHVDC links connected to island systems,” *IEEE Trans. Power Syst.,* vol. 26, no. 2, pp. 783–793, May 2011.

[19] L. Zhang, L. Harnefors, and H.-P. Nee, “Interconnection of two very weak ac systems by VSC-HVDC links using power-synchronization control,” *IEEE Trans. Power Syst., vol. 26, no. 1, pp. 344–355, Feb.* 2011.

[20] L. Zhang and H.-P. Nee, “Multivariable feedback design of VSC-HVDC connected to weak ac systems,” in *Proc. PowerTech,* Bucharest, Romania, 2009, pp. 1–8.

[21] S. Skogestad and I. Postlethwaite, *Multivariable Feedback Control: Analysis and Design, 2nd ed. West Sussex, U.K.: Wiley, 2005.*

[22] P. Kundur, *Power System Stability and Control. New York, NY,* USA: McGraw-Hill, 1994.

[23] J. Grainger and W. Stevenson, *Power System Analysis. New York,* NY, USA: McGraw-Hill, 1994.

[24] P. M. Anderson and A. A. Fouad, *Power System Control and Stability,* 2nd ed. New York, NY, USA: IEEE, 2003.

[25] B. Gao, G. K. Morison, and P. Kundur, “Voltage stability evaluation using modal analysis,” *IEEE Trans. Power Syst., vol. 7, no. 4, pp.* 1529–1542, Nov. 1992.