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HVDC Light: Transmission Technology Simulation Study & Application to Indian Grid

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Abstract— The key driver for deployment of sustainable Micro Grids in developing countries like India is need to provide electricity in remote & rural areas, energy security especially in urban areas and power quality. The enabling technologies like HVDC Light will play an important role in the success of Micro Grids. HVDC Light is the most interesting power transmission technology developed for several decades. It is ideal component in transmission network, which can control both active & reactive power instantaneously. HVDC Light/Voltage Source Converter (VSC) technology provides key benefits like controllability, compact modular design, ease of system interface and low environmental impact. This paper describes Indian Power scenario, Concept of Micro Grids, different issue faced in implementation of Micro Grids. This paper also deals with Indian Grid, renewable potential in India, HVDC Light Technology and application of HVDC Light to Indian Transmission grid so as to build reliable & stronger grid for future. This paper also includes MATLAB Simulation for HVDC Light with mathematical analysis & output waveforms are verified as per mathematical analysis.

Index Terms— DG, DGR, Micro Grid, HVDC Light, HVDC Plus, VSC, PWM, IGBT.

1 Introduction

In developing countries like India, most people in remote areas are far away from benefits of the ongoing electrification process. Since there is no power network available to connect the isolated villages to the central or state grids. In this connection, the Government had long before initiated the process of rural electrification through renewable and other locally available distributed generation resources. On the other hand, people in semi-urban areas are not able to fully meet with their energy requirements. For people in urban area, the focus in on power quality and reliability issues. This is due to the geographical diversity and customer area priority levels set by the Government. Owing to these demarcations, the theme of Micro Grids in developing countries has a different perspective and broader scope for discussion. In India, though there is an initiative for the encouragement of Micro Grids, there is a long way to go in overcoming certain hurdles. There is a strong regulatory framework for encouraging the independent renewable energy generation which constitutes the building blocks for Micro-Grids. The current on-going rural electrification programs are mainly with the renewable generation. The focus is now on the challenges to be faced in dealing with the adoptability of these DG/DERs in Micro Grid. [1] Main challenges are listed below-

1. Co-ordination issue with DG/DERs.
2. Successful parallel operation of Micro Grid with network.
3. Reactive Power Compensation
4. Lack of Clean & Reliable Source
5. Unstable Grid
6. Voltage fluctuations
7. Unreliable supply
8. Requirement of Back Start Capability in Blackouts
9. Power quality related problems

The enabling technologies like HVDC Light will play an important role in the success of Micro Grids. HVDC Light Technology is the most suitable interconnecting component for Micro Grid. HVDC Light as name indicates it is DC transmission technology based on VSC (Voltage Source Converter) using latest semiconductor technology IGBT (Insulated Gate Bipolar Transistor) .This technology provides converter switching speed 27 times more than traditional HVDC system. This technology is introduced by ABB in 1990s.HVDC light makes it economically feasible to connect small scale, renewable power generation plants to the main AC grid. Using the very same technology, remote locations such as islands, mining districts, and drilling platforms can be supplied with power from the main grid, thereby eliminating the need of inefficient local generation. The voltage, frequency, active and reactive power can be controlled precisely and independent of each other. It can used to transfer power up to 1200MW. [2]

The general overview of this paper is as follows. In Section 2, overview of HVDC Light Technology is discussed. Section 3 presents, HVDC Light Transient Steady State Model in d-q reference frame, Section 4 focus on Indian grid scenario, renewable energy potential in India & different challenges faced by Indian grid. Section V includes application of HVDC Light to Indian grid so as to build reliable & stronger grid for future. This paper also includes MATLAB Simulation and HVDC Light mathematical analysis, given in section VI. In this paper DC Voltage, Phase to phase Inverter Voltage, AC Load

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ISSN 2229-5518

Voltage, Modulation Index are simulated and waveforms are verified as per mathematical analysis. Section VII concluded the paper.

2 HVDC LIGHT TECHNOLOGY OVERVIEW

It is also known as HVDC Plus or VSC based Transmission Technology.

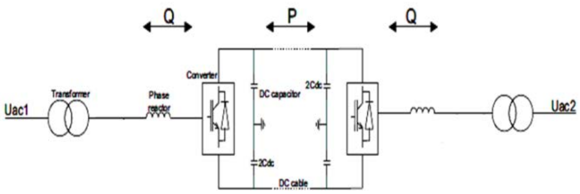

Figure 1:-HVDC Light System [3]

As Shown in Figure 1, An HVDC light system primarily consists of three parts: a rectifier station, an inverter station and high voltage dc transmission cables or lines. Two VSC stations are connected to ac systems via equivalent impedance representing the converter transformer and reactor between the VSC and the AC system. On DC side of each station, a capacitor bank is connected. Depending on the direction of active power flow, one station works as a rectifier while the other operates as an inverter. Each VSC station has two degrees of control freedom. One degree is used for reactive power control while the other degree is used for active power or dc voltage control.[4]

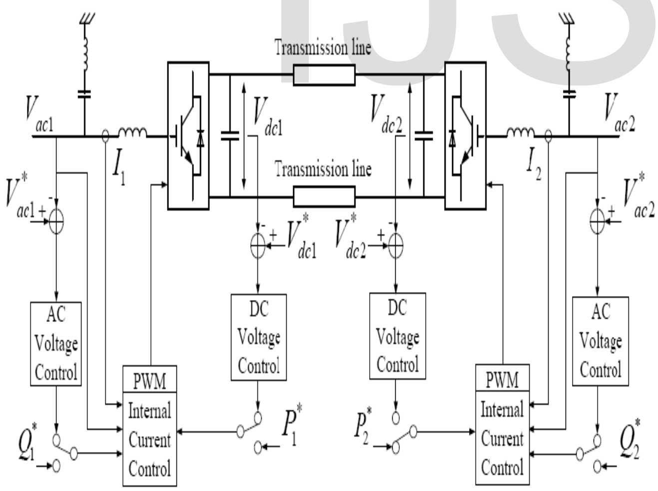

Figure 2:- Configuration of HVDC Light System [4]

The HVDC light system, as shown in figure 2, allows fully independent control of active and reactive powers within the operating range of design. Normally, each station controls its reactive power independent of the other station. However, the flow of active power in the dc transmission system must be balanced, which means that the active power entering the HVDC system must be equal to the active power leaving it, if neglecting the losses in the dc system. To achieve this power balance, one of the VSC stations has to control the dc voltage, while the other VSC station should be designed to control active power. Both stations contain either reactive power or ac voltage support control functions .In figure represent measured and reference dc voltages of the VSCs on the left and right sides of the HVDC light system, V_{ac1}, V^*_{ac1}, V_{ac2}, and V^*_{ac2} stand for measured and reference voltages of the two ac systems, and , and Q^*_{ac2} signify the real and reactive power references of the VSCs on the left and right sides with power flowing into each VSC defined as positive. [4]

2.1 HVDC Light Advantages:

The following factors make VSC-based transmission attractive:

- Independent control of reactive and active power
- Reactive control independent of other terminal(s)
- Simpler interface with ac system
- Compact filters
- Provides continuous ac voltage regulation
- No minimum power restriction
- Operation in extremely weak systems
- No commutation failures
- No restriction on multiple in feeds
- No polarity reversal needed to reverse power
- Black-start capability
- Variable frequency [5]

2.2 HVDC Light Applications:

Due to advantages provided by HVDC light, it is used in the following applications:

- Fast restoration after blackouts: HVDC Light can efficiently aid grid restoration after a blackout. The voltage support, frequency support and fast time response provided by HVDC Light are much needed during such conditions. [7]
  For example, in August 2003, when the north-east USA experienced a blackout, the Cross Sound Cable Project (which interconnects Connecticut and Long Island) provided voltage and frequency support, and thereby played a major role in the restoration of power to the grid. Black-start capability, the support provided to the AC grid by the converter stations, is also an important feature. Black-start allows for an HVDC Light system to greatly decrease the time for AC grid restoration
- City centre in feed: City centers are characterized by a high power demand and significant network constraints. HVDC light can play an important role here.[6]
- Small, isolated remote loads: Places that are located far away from the grid and that don't have their own generation can be powered via HVDC light. [6]
- Connecting wind farms: HVDC light can handle the variable frequency in the wind farm and the wind farm is also electrically isolated from faults in the shore grid.
- Underground power links: When it is (nearly) impossible to obtain a permit for an AC overhead line, HVDC light can play an important role.

ISSN 2229-5518

- Powering islands: HVDC light with underground sea cables is perfect for this application.
- Offshore platforms: HVDC light with underground sea cables is perfect for this application. An example is the power delivery to the Troll A gas platform with an HVDC Light with a rating of 84 MW and ±60 kV DC.
- Multi-terminal systems: With HVDC light, three or more converter stations can make up a HVDC grid a lot easier than with LCC HVDC. Because the HVDC light converters are voltage controlled, there is no need to balance the currents like in LCC HVDC.[9]
- Active and Reactive Power Flow Control:A one-phase equivalent circuit diagram of one converter station of a VSC HVDC link is shown in Figure 3.The total converter station consists of valves, phase reactor, filter bus and power transformer. The fundamental base apparent power at the filter bus between the converter reactor and the AC filter is

$$Sb = P + jQ$$

The active power component between converter and filter bus is given by:

$$P = \frac{UF.UC.\sin\delta}{Xphasereactor}$$

Whereas the reactive power component between converter and filter bus is given by:

$$Q = \frac{UF(UF - UC.\cos\delta)}{Xphasereactor}$$

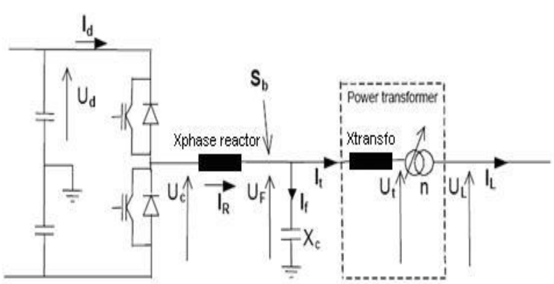

Figure 3: Circuit diagram of a VSC HVDC converter Station [2, 11]

Where δ is the phase angle difference between the Filter bus voltage UF and the converter voltage UC. Above Formulas assume a lossless phase reactor.
Control of active power flow by VSC HVDC is accomplished by changing the phase angle difference δ and control of reactive power flow is realized by changing the voltage amplitude difference between converter bus and filter bus. The converters PWM control can change the converters voltage angle and amplitude. Thus, active and reactive power can be controlled independently & almost instantaneously. [8,10]

- Improved grid reliability: HVDC Light System Improves grid reliability by improving the condition of connected AC network.[2]

2.3 Practical examples of HVDC Light System:

In the last few years the voltage source based HVDC became popular; more than eleven (11) systems are in operation. In addition to ABB, manufacturers like Siemens and Areva also offer a similar system. The manufacturers are working on large IGBT based HVDC systems which can compete with the classical thyristor based HVDC and suitable to form DC networks.

HVDC Light technology is not yet implemented in India but in Australia, at Direct Link and Murray link, we have two such examples where HVDC Light technology with underground DC-cables has been implemented in a competitive, market-oriented network service. [2]

Examples of HVDC Light Installations and pictorial appreciation of this technology in the World:

TABLE 1
PRACTICAL EXAMPLES OF HVDC LIGHT

Project	Year	Capacity	Length	Remark
Gotland, Sweden	1999	50MW ±80kV	2x70km Cables	Connects wind farm to load centre
Direct link, Australia	2002	3x60 MW ±80kV	6x65 km	Connects two regional electricity markets.
Cross Sound Cable , U.S.	2002	330 MW ±150kV	2x42km	Power transmission to long Island.
Murray Link, Australia	2002	200 MW ±150kV	2x180km	Connects two regional electricity markets & controls power flow.
Estlink, Estonia-Finland	2006	350 MW ±150kV	2x105 km	Improved security of the electricity supply in the Baltic States and Finland.

[2]

HVDC Light technology is available up to 1200 MW. Research is going on for developing HVDC Light Technology beyond 1200MW & to increase its cost effectiveness so as to compete with conventional HVDC system. Considering the advantages & popularity of HVDC Light System, it may shortly get implemented in India.

Thus the Indian Transmission grid & Application of HVDC Light technology to Indian grid is discussed in this paper.

ISSN 2229-5518

3 HVDC LIGHT TRANSIENT STEADY STATE MODELS IN D-Q REFERENCE FRAME

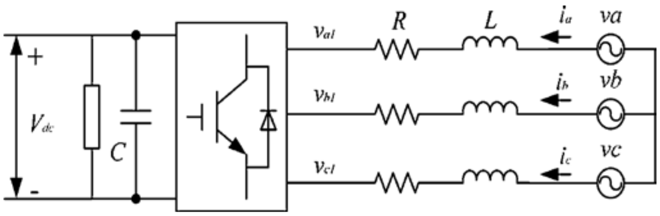

Figure 4: Equivalent system model of a VSC station. [4]

Fig. 4 depicts the equivalent system model of a VSC station connected to an ac system. A capacitor is shunt connected across the dc side of the voltage source PWM converter, and the shunt resistor across the dc bus models the power loss in the VSC station. The voltages v_{a1} , v_{b1} , and v_{c1} represent the three-phase line-to-neutral voltages injected by the PWM converter onto the ac system, and the voltages v_a , v_b , and v_c signify the three phase ac-system line-to-neutral voltages at the point of common coupling (PCC). The converter transformer and reactor between the VSC and the PCC are represented as a series combination of a resistor R and an inductor L.

In the d–q reference frame, the voltage balance equation at the interconnection of converter and ac system is

$$\begin{bmatrix} vd \\ vq \end{bmatrix} = \mathrm{R}\begin{bmatrix} id \\ iq \end{bmatrix} + \mathrm{L}\,\frac{d}{dt}\begin{bmatrix} id \\ iq \end{bmatrix} + w_s \times \mathrm{L}\begin{bmatrix} -iq \\ id \end{bmatrix} + \begin{bmatrix} vd1 \\ vq1 \end{bmatrix} \tag{1}$$

Where w_s is the angular frequency of the ac system voltages. Also, v_d , v_q , v_{d1} , and v_{q1} represent the d and q components of the PCC voltages and the VSC output voltages, respectively. The currents id and iq represent the d and q components of the current flowing between the ac system and the VSC.

Equation (1) can be expressed by a complex equation (2) using space vectors, in which v_{dq} , i_{dq} , and v_{dq1} are instantaneous space vectors of PCC voltage, line current, and VSC output voltage. Under the steady-state condition, (2) becomes (3), where V_{dq}, V_{dq1} , and I_{dq} stand for the steady-state space vectors of the PCC and VSC output voltages and line current.

$$\mathrm{v_{dq}} = \mathrm{R} \times \mathrm{i_{dq}} + \mathrm{L}\frac{\mathrm{d}}{\mathrm{dt}}\mathrm{i_{dq}} + \mathrm{jw_s\,L} \times \mathrm{i_{dq}} + \mathrm{v_{dq1}} \tag{2}$$

$$\mathrm{V_{dq}} = \mathrm{R} \times \mathrm{I_{dq}} + \mathrm{jw_s\,L} \times \mathrm{I_{dq}} + \mathrm{V_{dq1}} \tag{3}$$

In the PCC voltage orientation frame, the PCC d-axis voltage is constant and the q-axis voltage is zero. Thus, the instantaneous active and reactive powers transferred from the ac system to the VSC are proportional to the d- and q-axis currents, respectively, as shown by (4) and (5).

$$p_{ac}(t) = v_d i_d + v_q i_q = v_d i_d \tag{4}$$

$$q_{ac}(t) = v_q i_d - v_d i_q = -v_d i_q \tag{5}$$

In terms of steady-state conditions, $V_{dq} = V_d + j0$ if the d-axis of the reference frame is aligned with the PCC voltage position. Assuming $V_{dq1} = V_{d1} + jV_{q1}$ and neglecting the resistance, the current flowing from the ac system to the VSC is

$$I_{dq} = \frac{V_{dq1} - V_{dq}}{jX_L} = \frac{V_{d1} - V_d}{jX_L} + \frac{V_{q1}}{X_L} \tag{6}$$

Where $X_L = jw_s L$ is the reactance of the converter transformer and reactor between the VSC and the PCC.

Using passive sign convention for the converter, power flowing from the ac system to the VSC is positive. Thus, the power transferred to the VSC from the ac system can be computed as $P_{ac} + jQ_{ac} = V_{dq} I_{dq}^* = V_d I_{dq}^*$ By solving this power equation together with (6), (7) is obtained. According to (7), the ac system active and reactive powers Pac and Qac are controlled through q and d components V_{q1} and $V_{d1}$of the VSC voltage injected onto the ac system. If the resistor R is considered, similar power control characteristics of the VSC still exist under both steady-state and transient open-loop control conditions, as in

$$P_{ac} = -\frac{V_d V_{q1}}{X_L} \quad Q_{ac} = -\frac{V_d}{X_L}\left(V_d - V_{d1}\right) \tag{7}$$

4 INDIAN GRID, RENEWABLE ENERGY SCENARIO & CHALLENGES FOR INDIAN GRID

4.1 Indian Transmission Grid Scenario:

The Indian Power system for planning and operational purposes is divided into five regional grids. Synchronization of all regional grids will help in optimal utilization of scarce natural resources by transfer of Power from Resource centric regions to Load centric regions. Grid Management in India is carried out on a regional basis. The country is geographically divided in five regions namely, Northern, Eastern, Western North Eastern and Southern.

Peculiarities of Regional Grids in India are shown below:

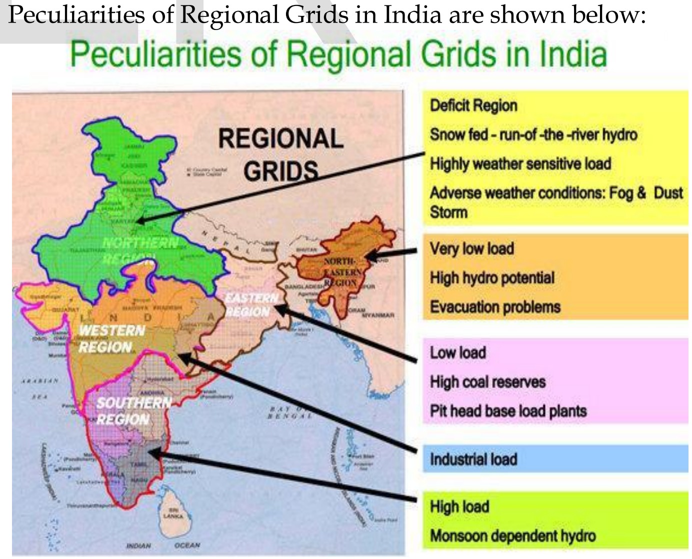

Figure 5: -Indian Regional Grids

4.2 Renewable Energy Potential in India:

Ample of Renewable Energy is available in India. Out of Main sources for Electricity in India 12% energy is available from Renewable sources .There are many problems involved with renewable generation & grid synchronism. So as to effectively utilize the available renewable energy & to overcome the problems HVDC Light System plays an

ISSN 2229-5518
important role. In past several years in India has significant growth in renewable energy generation. Figure 5 shows installation of various renewable energy recourses as in the year 2009, current scenario in year 2015 and projected installed capacity in the year 2032.[1]

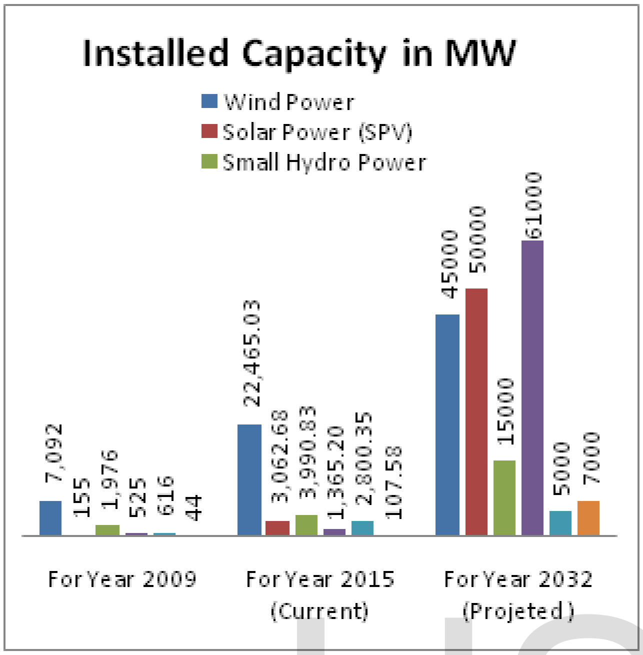

Figure 6: - Renewable Energy Potential in India [1]

4.3 Statement of Problems faced in Indian Transmission Grid:

Following are the serious problems faced in Indian Transmission Grid-

1. Reactive power compensation issue: As the most of load in India is agricultural because of availability of ample water resource & irrigation facilities. Also day by day there is substantial increase in industrial load due to growing development in India. The inductive load is predominant because of substantial agricultural pump load and industrial development. The power factor of induction motors that are used for both agricultural & industrial purpose is generally very low also the equipment used such as Computers, T.V., Mixers, Washing machine , Blower etc are responsible to reduce power factor. Therefore this load draws sizable reactive power from the system. Apart from the requirement of loads, lines and transformers also consume some reactive power. So there is need of compensating equipment's. If Compensation is not provided then this reactive power is drawn from the generating units through the transmission lines. This causes large voltage drop and heavy line losses, thereby, showing the apparent loading of lines and generating unit and effect in reducing the capacity of generating units as well as transmission lines and substation.
2. Lack of clean and reliable energy sources: There many problems involved in grid connection of renewable plant such as
   - Unstable grid
   - Voltage fluctuations
   - Unreliable supply
3. Requirement of back start capability in blackouts: Two severe power blackouts affected most of northern and eastern India on 30 and 31 July 2012. The 30 July 2012 blackout affected over 300 million people and was briefly the largest power outage in history, counting number of people affected, beating the January 2001 blackout in Northern India. (230 million affected)The blackout on 31 July is the largest power outage in history. The outage affected over 620 million people, about 9% of the world population, or half of India's population, spread across 22 states in Northern, Eastern, and Northeast India. An estimated 32 gigawatts of generating capacity was taken offline. Electric service was restored in the affected locations between 31 July and 1 August 2012. Following factors were responsible for the two days of blackout:
   1. Weak inter-regional power transmission corridors due to multiple existing outages (both scheduled and forced)
   2. High loading on 400 kV Bina–Gwalior–Agra link
   3. Loss of 400 kV Bina–Gwalior link.

   Hence there is need of suitable element which provides necessary voltage and power support in case of blackouts for restoration.
4. Power/Voltage quality & stability related problems.

5 Towards Smart Grid: Application Of Hvdc Light To Indian Grid

5.1 HVDC Light Application to Indian grid:

After analyzing the problems faced by Indian network if we propose the HVDC Light technology followed by suitable renewable generation like solar, wind etc. we can overcome the many of above problems and it will offer following technical benefits too.

- Black Start Capability-If HVDC Light is proposed by identifying critical substation such that if that substation goes into dark then major grid or part of grid will be affected and installation of HVDC Light technology at identified substation with suitable voltage rating will provide the required back start capability by providing required voltage & frequency support during black outs also it will feed the important loads during Blackouts like static generator.Thus the Incidences like northern and eastern India Blackout on 30 and 31 July 2012 can be avoided or its effect could be minimized using HVDC Light System.
- Reactive Power Compensation- With HVDC Light instantaneous Active & Reactive Power Control is

ISSN 2229-5518

possible. It will also improve the condition of connected AC network.

- City center feed- HVDC Light with Suitable Renewable Source can feed city center.
- Reliable Supply to Important Loads-Some important loads like EHV Consumers / Co-generation Plants demanding uninterrupted power Supply from grid will also get benefited & will have uninterrupted & Improved Quality of Supply.
- Environmental Impact-With DC Underground Cable Transmission no question of problems like ROW, thus has low environmental impact.
- Clean & Reliable Renewable Interconnections-Now days, awareness about Renewable energy is increasing day by day. Many applications regarding feasibility for grid connection for Renewable Energy plants are coming in respective authority offices. Many Plants got feasibility permission & commissioning is in process.

  There many problems involved in grid interconnection of renewable generation, all problems can be overcome with HVDC Light Technology, Thus the renewable potential can be effectively utilize.

6 MATLAB SIMULATION & ANALYSIS

6.1 SIMULATION:

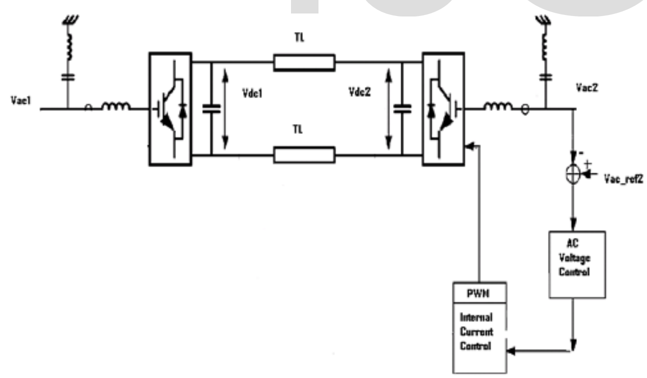

Figure 7: HVDC Light Block diagram implemented in Matlab

6.2 CIRCUIT DESCRIPTION:-

1. VOLTAGE SOURCE:

MVA Ratings: 10 MVA
Power Ratings: 25KW

Frequency Ratings: 50Hz
X/R Ratio: 5

2. TRANSFORMER:

Voltage Ratings: 25KV/600V
KVA Ratings: 50KVA
Connections: Star-Delta

3. DC LINE PARAMETERS:

Resistance/Km: 0.015 Ohm/km
Inductance/Km: 0.792 e-3 H/km
Capacitances/Km: 14.4e-9 F/km

4. LOAD PARAMETERS:

Power Ratings: 50KW
Voltage Ratings (Vrms): 380V
Frequency Ratings: 50Hz

5. IGBT:

Carrier frequency: 2 KHz

6.3 OUTPUT WAVEFORMS:-

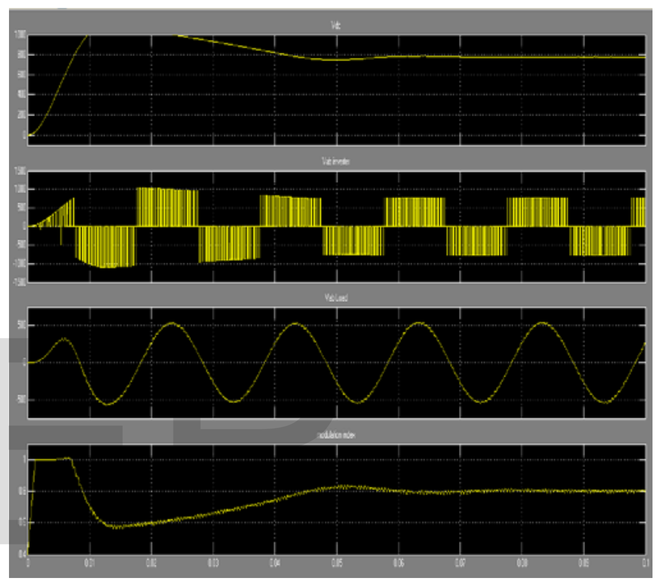

Figure 8: DC Voltage, Voltage across inverter, AC Voltage across load, Modulation index

Following features of HVDC Light are verified from simulation-

1. Variable frequency interconnection (ie source & Load with a different frequencies)
2. Provides continuous ac voltage regulations
3. Active power entering & leaving the system is balance for HVDC Light system
4. Output waveform verification-As expected the peak value of the load voltage is 537 V (380 V rms), as it is regulated to 380Vrms. In steady state, the mean value of the modulation index is m = 0.80.Modulation index is the ratio of Modulated voltage to the reference voltage. It generally varies between 0 to 1. The fundamental component Phase to Phase AC voltage through IGBT Inverter is given by,

$$Vab(rms) = \frac{\sqrt{3} \times Modulation\ Index \times Vdc}{2\sqrt{2}}$$

$$Vab = 0.612 \times m \times Vdc$$

m=0.80, Vab rms = 380 V rms (as per simulation)
Then Vdc comes to be,

$$Vdc = \frac{Vab(rms)}{0.612 \times 0.80} = \frac{380}{0.612 \times 0.80}$$

$$Vdc = 776V\ (calculated)$$

It is verified from output waveform that Vdc =776V. Thus the simulation is verified.

7 Conclusion

HVDC Light is a new technology that has been specifically developed to match the requirements of the new competitive electricity markets. It provides the ability to connect renewable generation to the AC grid. It allows us to supply power to remote locations and islands replacing local diesel generation. It is the ideal component for building strong Micro Grids. The technical merits are that by virtue of their standardized prefabricated modular constructions which lead to short delivery times, it is re-locatable and can be expanded to meet growing demand. Moreover, a key advantage is that it provides accurate control of the transmitted active power and independent control of the reactive power in the connected AC networks. A pair of lightweight DC cables can be laid direct in the ground in a cost-effective way which is comparable to or less than a corresponding total life cycle cost of AC overhead line. As opposed to an overhead line, an underground cable pair has no visual impact on the landscape. Usually it's much easier to obtain permission and public approval for an underground cable transmission compared with an overhead line, especially in residential areas.

Application of HVDC Light to Indian network just not only provides required reactive power compensation but also improves the condition of connected network, It will also provide important feature like back start capability to grid .Thus we will get Stable grid with fully controlled transmission line. By providing required reactive power compensation, this will help in reducing the drawl of reactive power from local generators at various generating stations as well as other generating centers of the respective state and will improve the voltage conditions as well as reduces the line losses. Research is going on for developing HVDC Light Technology beyond 1200MW power transmission & to increase its cost effectiveness so as to compete with conventional HVDC system. Considering the advantages & popularity of HVDC Light System, it may shortly get implemented in India.

7 References

[1] V.S.K.Murthy Balijepalli, S.A.Khaparade, C.V. Dobariya, "Deployment of MicroGrids in India", IEEE 2010.

[2] ABB , "Its Time to Connect –Technical Description of HVDC Light Technology".

[3] Shri Harsha J , Shilpa G N , Ramesh E , Dayananda L N , Nataraja C , "Voltage Source Converter Based HVDC Transmission" , IJESIT , Vol.1 , Issue 1, Sept 2012.

[4] Shuhui Li, Timothy A. Haskew, "Control of HVDC Light System Using Conventional and Direct Current Vector Control Approaches" , IEEE Transactions on Power Electronics , Vol-25 , No-12 , Dec 2010.

[5] S. Mohamed Yousuf , M. Siva Subramaniyan , "HVDC & FACTS in Power System" , IJSR , 2319-7064.

[6] Gunnar Asplund , "Application of HVDC Light to Power System Enhancement" IEEE Winter Meeting Jan 2000 , Singapore.

[7] Stefan G Johansson , Gunnar Asplund , Erik Jansson & Roberto Rudervall , "Power System Stsbility Benefits with VSC DC Transmission Systems" Cigre Session 2004 , B4-204.

[8] Brahim Bekki , Mohamed Moudjahed , Mouhamed boudiaf , "Transmission System Transient Stability Enhancement based on VSC-HVDC" Journal Electrical Engineering.

[9] Lars Weimers , ABB, "HVDC Light –The Transmission Technology of The Future " , Orkuping 2001.

[10] Ramesh Gantha , Rasool Ahemmed , "Improvement of Rotor Angle Stability & Dynamic Performance of AC/DC Interconnected Transmission System" , IJETT, Volume 4 Issue 5 May-2013.

[11] Alok Kumar Mohanty , Amar Kumar Barik , "HVDC Light & Facts Technology: A Modern Approach to Power System Interconnections" , IJERA , Vol.2 , Issue 2 , Mar-April-2012, PP.1331-1336.