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Back-To- Back HVDC Modular Multilevel Converter Operating As Power Quality Conditioning System

Nadimpally Anusha
PG Scholar, Department of EEE, Avanthi Institute of Engineering and Technology, Hyderabad, India.
E-mail: n.anusha.nkp@gmail.com

E Prasanna
Assistant Professor, Avanthi Institute of Engineering and Technology, Hyderabad, India.
E-mail: Prasanna.earati81@gmail.com

***Abstract* - Modular multilevel converters (MMCs) have recently piqued attention in the field of high-voltage direct-current (HVDC) transmission technology due to their unique properties. Three essential features of high-voltage direct current (HVDC) MMCs are intimately connected to the modulation and switching schemes utilised by the converters: power quality, converter cost, and system performance. For excellent power quality and performance, high switching frequencies and large cell capacitors are necessary, while for poor power quality and performance, low switching frequencies and tiny cell capacitors are required.In order to minimise the cost of the converter, a high frequency and a tiny cell capacitor are required. It is possible to obtain an appropriate choice of modulation and switching strategy viaan optimal trade-off between these opposing criteria is found.The primary goal of this thesis is to offer a realistic switching technique that is both simple and effective.for HVDC MMCs that strikes a compromise between the previously stated conflicting criteria An examination of the switching pattern of the converter in terms of mathematics, as opposed toAn investigation of the power quality and converter costs has been carried out in order to develop anMMCs that are linked to the grid face an optimization issue. Various goal functions are used.Convertor loss and other aspects of the stated optimization issue are being investigated. Minimising the amount of energy used, minimising voltage imbalance, and minimising computational load specifically, this thesis offers three approaches for achieving various objectives.**

***Index Terms*: Modular multilevel converters, voltage imbalance, power quality, cell capacitors**

I INTRODUCTION

In conventional power transmission networks, high-voltage alternating current (HVAC) technology is utilized to transport electric power. On the other hand, the necessity for more efficient transmission systems has prompted the introduction of modern transmission technologies such as high-voltage direct current transmission (HVDC). In the 1930s, ASEA, a Swedish industrial business, started developing high-voltage direct current (HVDC). The following are some of the most prominent technical benefits of high-voltage direct current technology:

As a consequence of these advancements, the adoption of this technology in power grids has been advocated. In 1951 and 1954, the Soviet Union and Sweden, respectively, developed the first high-voltage direct current transmission networks [1]. The converters in this set were designed using a line-commutated architecture with mercury-arc valves as switching devices. With the commissioning of the world's first thyristor-based high-voltage direct current (HVDC) station at Eel River, New Brunswick, Canada in 1972, Solid State Devices for Line-Commutated Converters and the replacement of mercury-arc valves started. The emergence of voltage-source topologies that could control reactive power accompanied the evolution of high-voltage direct current technology. In 1997, the world's first commercial voltage-source converter [3], which was placed in Hellsjön, Sweden, and worked on a two-level system, was commissioned. Later, in 2003 [4, for the first time, the modular multilevel converter (MMC) architecture is offered for commercial application. In terms of modularity and losses, MMC converters for high-voltage

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direct current (HVDC) systems surpassed two-level converters. In recent years, MMC has, as predicted, become a popular design for high-voltage direct current (HVDC) applications.

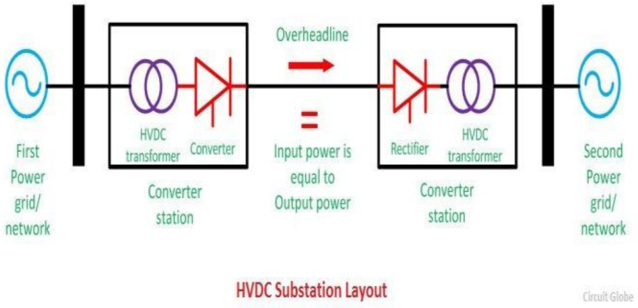


FIGURE 1 HVDC Layout.

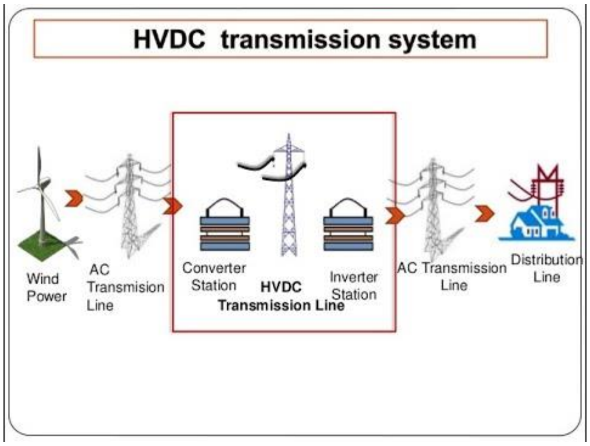
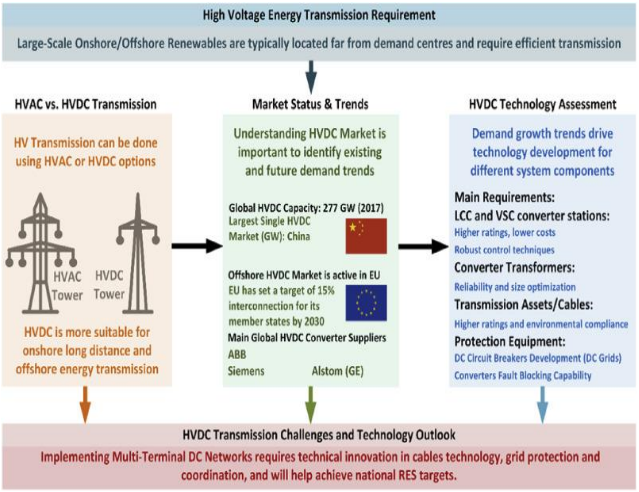


FIGURE 2 Schematic of HVDC.



High Voltage Energy Transmission Requirement

Large-Scale Onshore/Offshore Renewables are typically located far from demand centres and require efficient transmission

HVAC vs. HVDC Transmission

HV Transmission can be done using HVAC or HVDC options

HVDC is more suitable for onshore long distance and offshore energy transmission

Market Status & Trends

Understanding HVDC Market is important to identify existing and future demand trends

Global HVDC Capacity: 277 GW (2017)
Largest Single HVDC Market (GW): China

Offshore HVDC Market is active in EU
EU has set a target of 15% interconnection for its member states by 2030

Main Global HVDC Converter Suppliers
ABB
Siemens
Alstom (GE)

HVDC Technology Assessment

Demand growth trends drive technology development for different system components

Main Requirements:
LCC and VSC converter stations:
Higher ratings, lower costs
Robust control techniques
Converter Transformers:
Reliability and size optimization
Transmission Assets/Cables:
Higher ratings and environmental compliance
Protection Equipment:
DC Circuit Breakers Development (DC Grids)
Converters Fault Blocking Capability

HVDC Transmission Challenges and Technology Outlook

Implementing Multi-Terminal DC Networks requires technical innovation in cables technology, grid protection and coordination, and will help achieve national RES targets.

FIGURE 3 Challenges in HVDC.

II MODULAR MULTILEVEL CONVERTERS

An MMC HVDC station is generally shown in the picture, which is connected to an alternating current grid through a transformer at the point of common connection (PCC). Each converter phase is made up of two converter arms, each with N cells coupled together in a cascade

.

$$-v_{dc}+v_p+Ri_p+L_{arm}\frac{di_p}{dt}+L_T\frac{di_s}{dt}+v_g=0,$$

$$v_{dc}-v_n-Ri_n-L_{arm}\frac{di_n}{dt}+L_T\frac{di_s}{dt}+v_g=0,$$

$$v_s=\frac{v_n-v_p}{2},$$

$$i_s=i_p-i_n,$$

$$L_{eq}=\frac{L_{arm}}{2}+L_T.$$

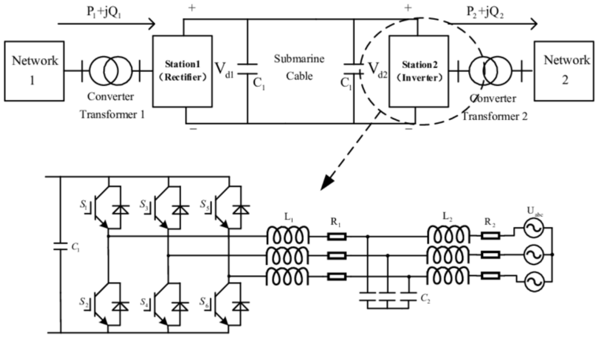


FIGURE 4 Structure of HVDC using MMC.

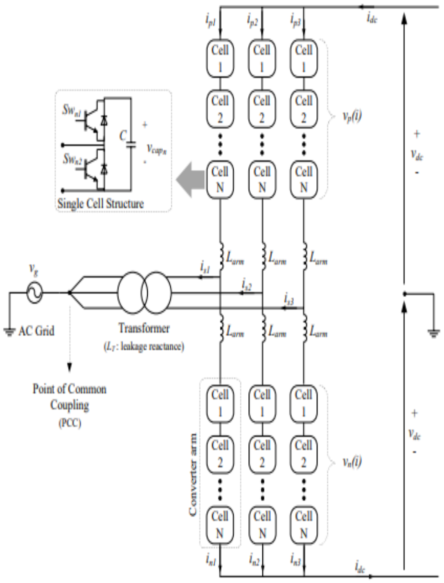


FIGURE 5 Schematic of MMC.

$$L_{arm}\frac{di_c}{dt} = v_c - Ri_c,$$

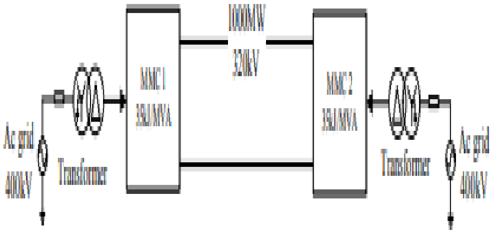
$$v_c = v_{dc} - \frac{v_n + v_p}{2},$$

$$i_c = \frac{i_p + i_n}{2}.$$

$$\begin{aligned} v_{p,n} = \frac{2V_{dc}}{N} + \frac{1}{2\omega C_{arm}^{eq} V_{dc}}(\pm\frac{S}{3m}\sin(\omega t - \varphi) \mp \frac{mP}{6}\sin(\omega t) \\ - \frac{S}{12m}\sin(2\omega t - \varphi) \pm \frac{k_{3rd}mP}{18}\sin(3\omega t + \varphi_{3rd}) \\ + \frac{k_{3rd}S}{12}\sin(2\omega t + \varphi_{3rd} + \varphi) \\ + \frac{k_{3rd}S}{24}\sin(4\omega t + \varphi_{3rd} - \varphi)), \end{aligned}$$

A. *Configuration of the HVDC:*

Modulating the insertion index and switching the cells in modular multilevel converters may be done in a few different ways. This thesis proposes the adoption of a novel switch.



The benchmark model is based on the INELFE interconnection [7], a real high-voltage direct current (HVDC) link between France and Spain. A point-to-point HVDC connection with an active power rating of 1000 MW and a reactive power rating of 300 MVAR serves as the benchmark. The nominal dc-side voltage is about 320 kV, and the converter connects it to a 400 kV alternating current network. As illustrated in Fig. 2.2, this arrangement is first modelled in PSCADTM/EMTDCTM and subsequently in a real-time simulator. In the PSCAD simulation, there are 40 converter levels (cells), but in the real-time simulation, there are 512 converter levels (cells).

Each converter station requires a competent control system in order to give the necessary power contribution. The basic control blocks for a grid-connected MMC are shown in Figure 1. The control structure may be divided into two levels based on broad principles: high-level control and low-level control. An outer control loop, an internal control loop, and a converter modulator are the three components of high-level control (or modulator). The outside controller controls the amount of power transmitted to the alternating current (alternating current) grid and sets the current reference signals to stabilise the converter dc voltage.

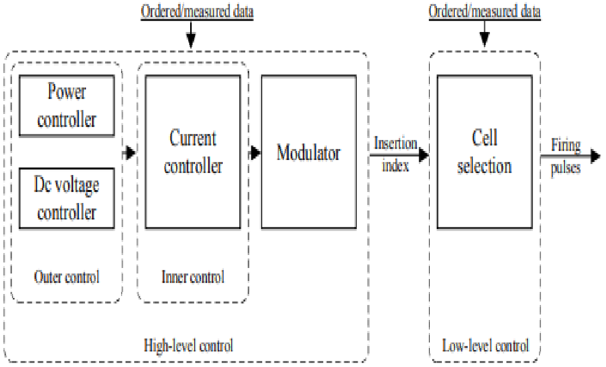


FIGURE 6 HVDC Control.

A reference signal that matches the normalised necessary voltage level of each converter arm is used as the insertion index for each converter arm. To compensate for this, each converter arm is equipped with a series-connected capacitor, which may be individually put into the current route or bypassed from the current path as needed.

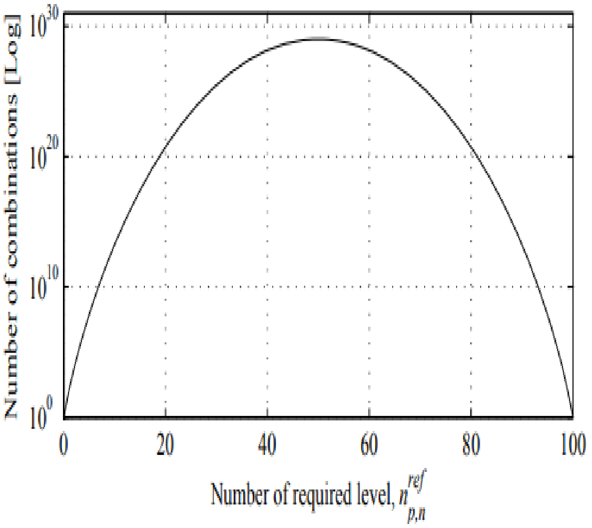


FIGURE 7 Converter cell configuration.

As a consequence, by combining the sum of the capacitor voltages that have been supplied, the total arm voltage is synthesised. Low-level control generates the firing pulses for each individual cell in the background, based on the voltage level required at each time step. The high-level control, for the most part, generates the reference signal for each converter arm, while the low-level control decides how many cells should be admitted and which should be rejected.

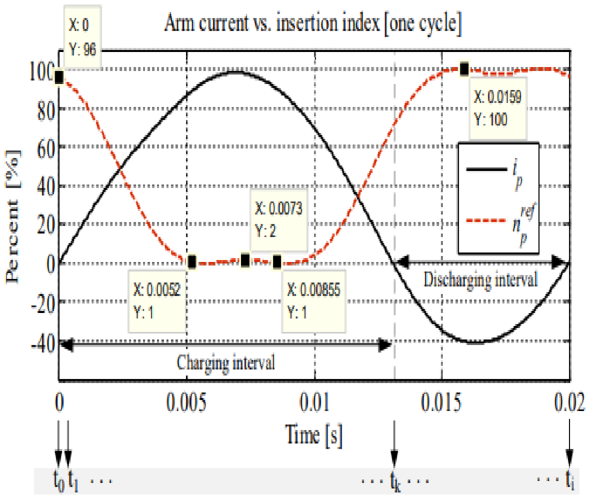


FIGURE 8 Cell performance.

While this is true, there are other permutations that might result in the required arm voltage level. The cell selection technique may be regarded of as a strategy for picking specific items from a collection of objects, assuming that the capacitor voltage levels in all cells are the same.

B. MMC Topologies:

Following are the various topologies available in modular multilevel converters

- Binary Inverters
- Trinary Inverters
- Assymetric Inverters
- H bridge Inverters
- Generalized Inverters.

The description of every types and its topology are shown below.

C. Binary MMC

The figure shown below shows the topology of the binary inverter.

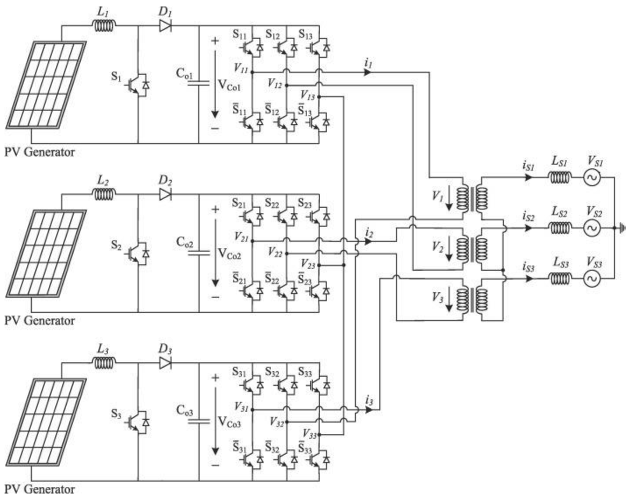
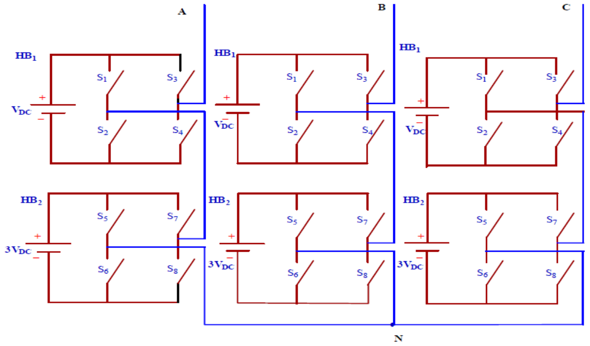


FIGURE 9 Binary MMC.

C. Trinary MMC:

The figure shown below shows the topology of the trinary inverter.



D. Asymmetric MMC:

The figure shown below shows the topology of the asymmetric inverter.

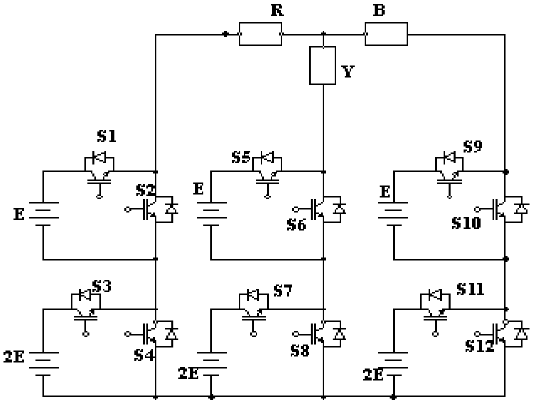


FIGURE 10 Asymmetrical inverter topology.

Bin-packing and knapsack problems, two problems that are quite similar, are well-known as NP-hard problems in the field of computer science. Solvers for NP-hard problems often take a long time to execute, making them unsuitable for creating online switching patterns in multi-core microprocessors. Off-line optimal solution research, on the other hand, may contribute in the development of heuristic strategies for addressing this kind of problem quickly.

A variety of modulation and cell selection strategies have been proposed since the MMC was initially reported in [4]. In contrast to today's technologies, early published solutions, such as carrier-based pulse width modulation, were mainly developed for acceptable system performance with no loss reduction strategy (PWM). The switching cells that will be employed at the carrier-reference crossover are identified using carrier-based PWM methods. The carrier frequency, which may be directly modified by the converter control system, is equal to the number of switching occurrences, also known as the switching frequency. Switching actions, on the other hand, control the ripple in capacitor voltage indirectly. This approach, according to the research, creates a substantial capacitor voltage ripple at low carrier frequencies, rendering it inappropriate for HVDC applications.

III SIMULATION RESULTS OF VSC HVDC

The simulation results of the modular multi level inverter based HVDC system are presented in this chapter All the simulations are carried out in MATLAB/SIMULINK.

A. *Description of VSC HVDC*

- Following are the parameters of the MMC HVDC system230 KV, 2000 MVA, and 50 Hz identical systems are used
- Systems are interconnected using 200 MVA, 100 KV DC
- A three-level Diode Clamped MLI is employed in the system modeling
- Sinusoidal pulse width modulation is used for producing the firing pulses
- The switching frequency used is 1.3 kHz.
- A 75 Km cable is used in the interconnection process
- A smoothing reactor is employed in the circuit
- Three-phase to ground fault is applied on AC side

The simulations are carried out with fault and without fault, conditions using the specifications as mentioned above of the VSC HVDC system.

B. *Schematic of VSC HVDC*

The schematic of the system under study consists of the following things, which is clear from the simulation diagram shown in the figure below

- Two identical AC systems
- Two Converter stations
- Fault block at the AC side in one of the two systems
- Filter for the Converters
- Pulse generation blocks for the VSCs
- Data analyzing block for observing the output waveforms

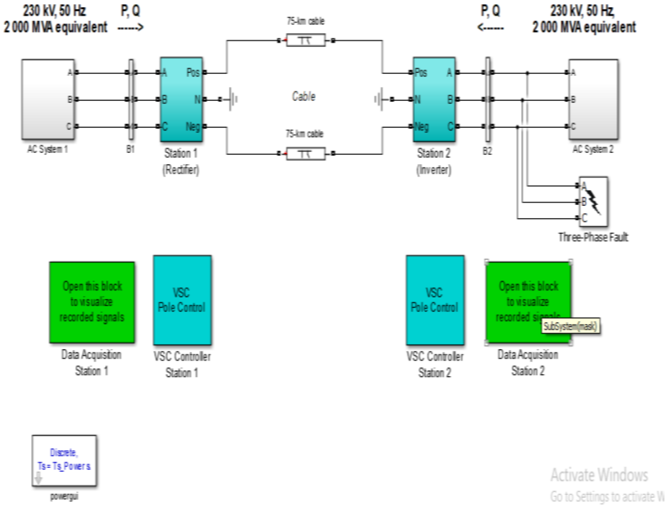


FIGURE 11 Main circuit of MMC HVDC.

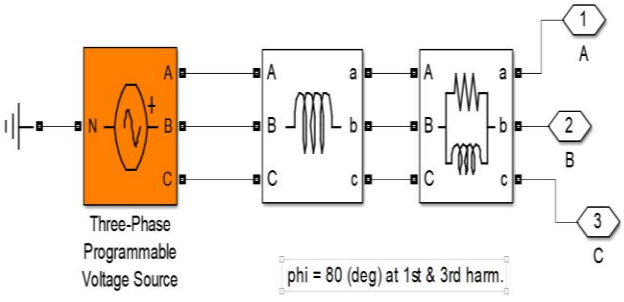


FIGURE 12 AC Source in System 1

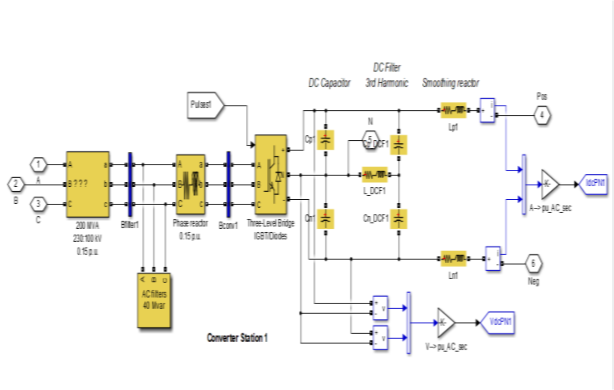


FIGURE 13 Sending end Stations 1

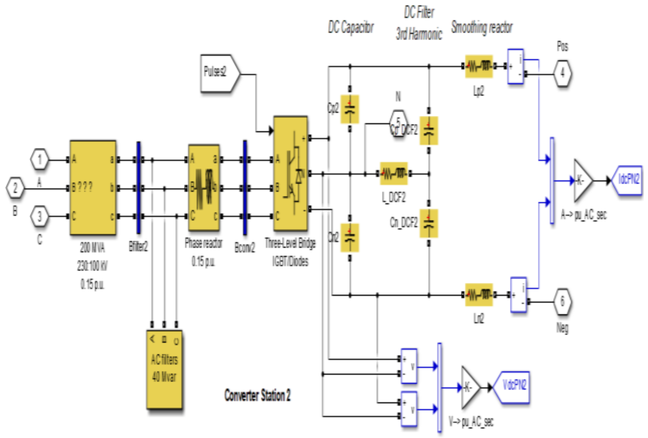


FIGURE 16 Receiving end stations 2

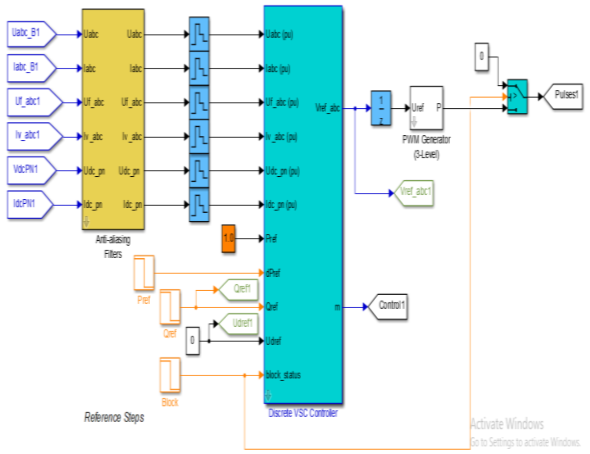


FIGURE 14 PWM pulses for MMC 1

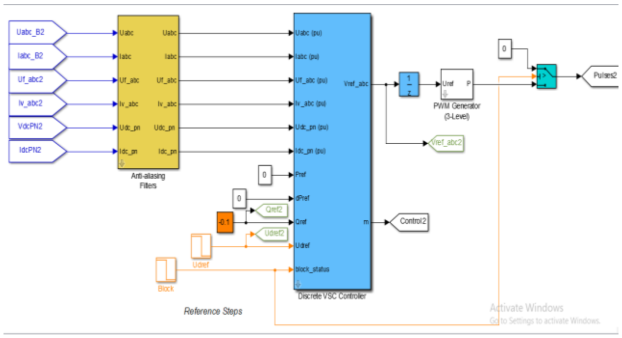


FIGURE 17 Modulation pulses for VSC 2

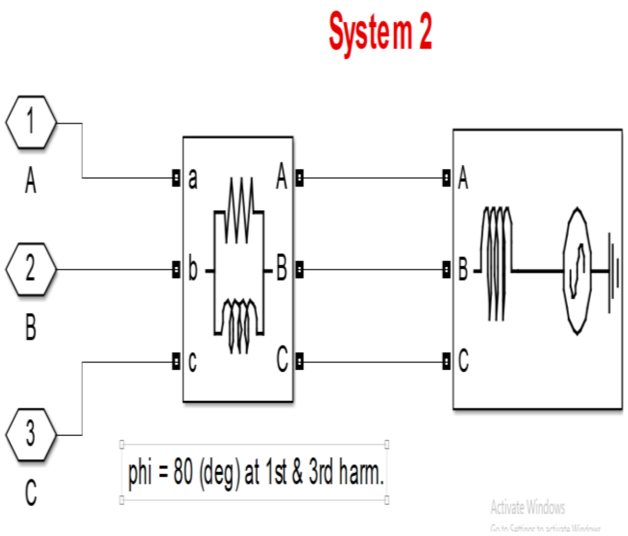


FIGURE 15 AC Source 2

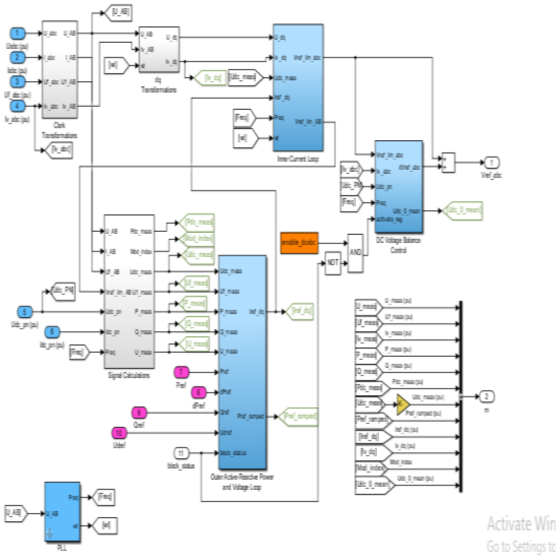


FIGURE 18 Discrete controllers for MMC

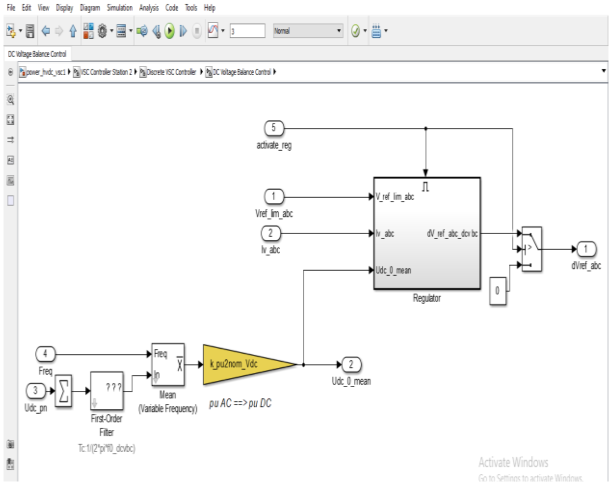


FIGURE 23 DC bus voltages balancing

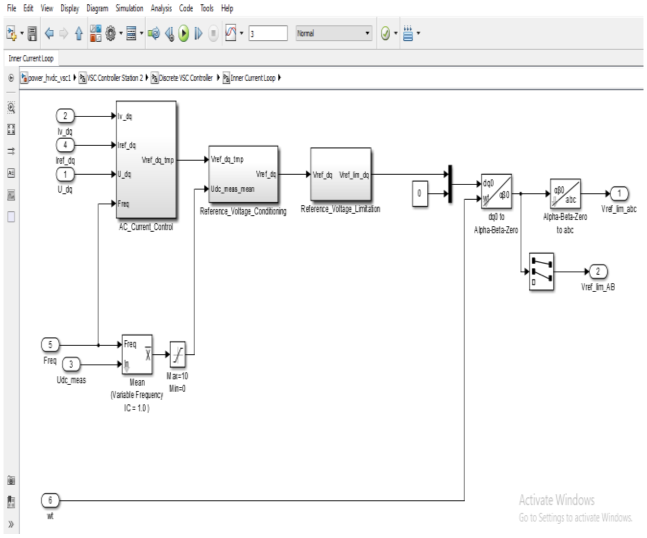
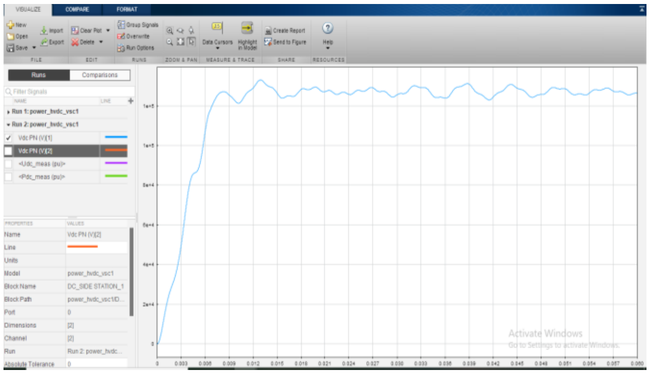


FIGURE 24 MMC current loop

C. *Output waveforms of system 1*



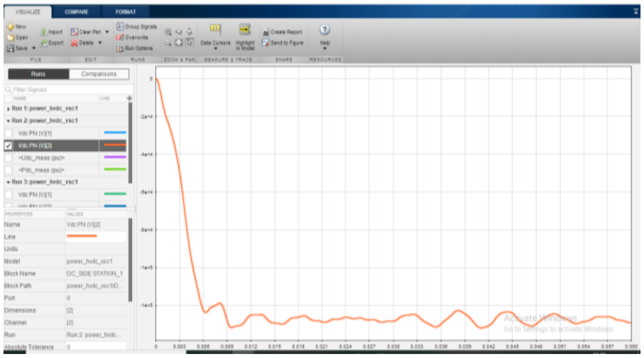


FIGURE 25 Positive and negative DC Voltages

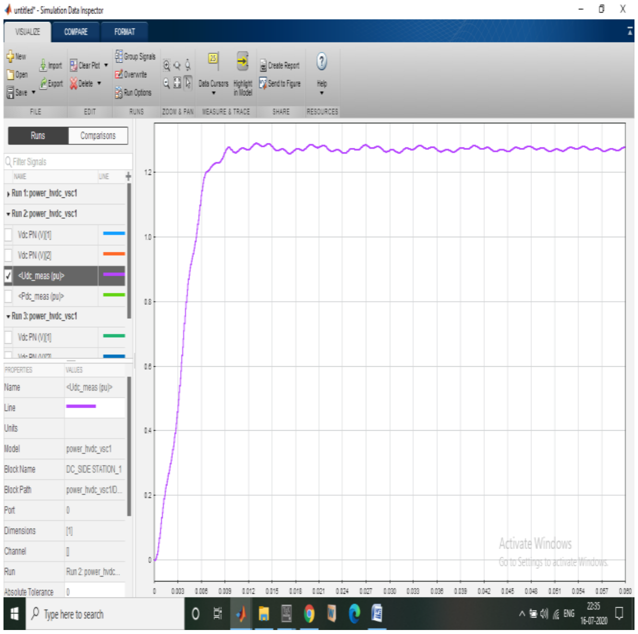


FIGURE 26 Reference DC Voltages

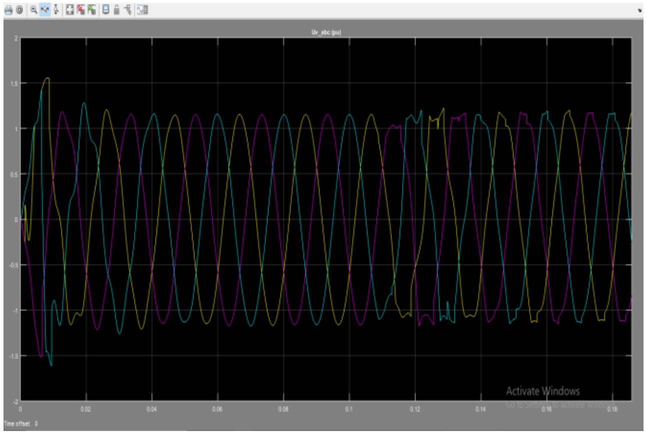


FIGURE 27 AC Voltage of first converter station

D. Output waveforms of system 2

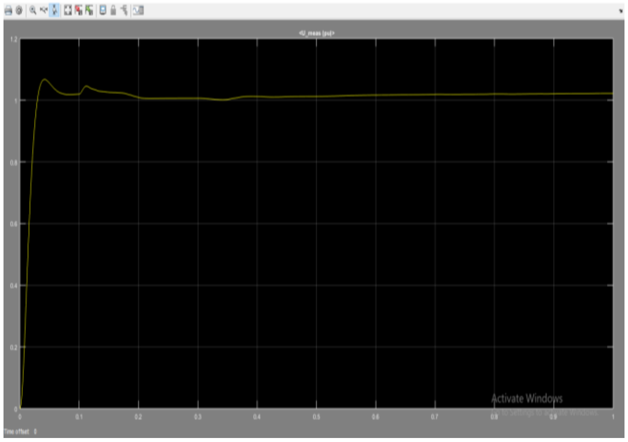


FIGURE 28 DC positive voltage

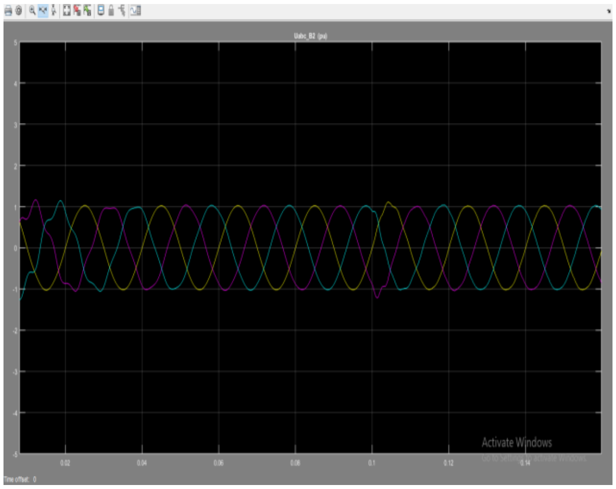


FIGURE 29 Three-phase balanced voltage after filtering

CONCLUSION AND FUTURE WORK

A. Conclusions

Following conclusions are made from the work carried out in this project

- Bulk power can be easily transmitted using HVDC
- If the HVDC is operated using VSC, then the quality of the output voltages improves.
- Usage of active power filter can be avoided by employing the VSC in HVDC systems.
- The real power and the reactive power balances are good with VSC HVDC systems

B. Future Work

However, the following aspects of VSC based HVDC are not addressed in this project, which are left as a future scope of this project. Some of those aspects are

- The multi-terminal VSC HVDC systems are not considered in this project; hence, if the same study can be performed on multi-terminal systems.
- Stability study is another important aspect, which is not considered in the present study. This work can be addressed in future studies.
- This technology can be applied to the grid integration of renewable, which is left as future work.

REFERENCES

[1] L. Gyugyi, "Unified power-flow control concept for flexible AC transmission systems," *Generation, Transmission and Distribution, IEE Proceedings C,* vol. 139, pp. 323-331, 1992.

[2] J. D. Ainsworth, M. Davies, P. J. Fitz, K. E. Owen, and D. R. Trainer, "Static VAr compensator (STATCOM) based on single-phase chain circuit converters," *Generation, Transmission and Distribution, IEE Proceedings-*, vol. 145, pp. 381-386, 1998.

[3] N. G. Hingorani, "High-voltage DC transmission: a power electronics workhorse," *Spectrum, IEEE*, vol. 33, pp. 6372, 1996.

[4] WorldBank, "Electric power consumption (kWh)," *World Development Indicators*, 30-03-2012 2012.

[5] L. Zhang, J.-Y.Song, J.-Y. Zou, and N. Wang, "High Voltage Super-Capacitors for Energy Storage Devices Applications," in *Electromagnetic Launch Technology, 2008 14th Symposium on*, 2008, pp. 1-4.

[6] A. M. van-Voorden, L. M. R. Elizondo, G. C. Paap, J. Verboomen, and L. v. d. Sluis, "The Application of Super Capacitors to relieve Battery-storage systems in Autonomous Renewable Energy Systems," in *Power Tech, 2007 IEEE Lausanne*, 2007, pp. 479-484.

[7] T. Sels, C. Dragu, T. Van Craenenbrock, and R. Belmans, "New energy storage devices for an improved load managing on distribution level," in *Power Tech Proceedings, 2001 IEEE Porto*, 2001, p. 6 pp. vol.4.

[8] R. Gupta, A. Ghosh, and A. Joshi, "Cascaded multilevel control of DSTATCOM using multiband hysteresis modulation," in *Power Engineering Society General Meeting, 2006.IEEE*, 2006, p. 7 pp.

[9] B. Heile, "Smart grids for green communications [Industry Perspectives]," *Wireless Communications, IEEE,* vol. 17, pp. 4-6, 2010.

[10] C. Marinescu, A. Deaconu, E. Ciurea, and D. Marinescu, "From Microgrids to Smart Grids: Modeling and simulating using graphs part II optimization of reactive power flow," in *Optimization of Electrical and Electronic Equipment (OPTIM), 2010 12th International Conference on*, 2010, pp. 1251-1256.

[11] M. A. S. Masoum, P. S. Moses, and S. Deilami, "Load management in smart grids considering harmonic distortion and transformer derating," in *Innovative Smart Grid Technologies (ISGT), 2010*, 2010, pp. 1-7.

[12] A. Molderink, V. Bakker, M. G. C. Bosman, J. L. Hurink, and G. J. M. Smit, "Domestic energy management methodology for optimizing efficiency in Smart Grids," in *PowerTech, 2009 IEEE Bucharest*, 2009, pp. 1-7.

[13] D. Povh, "Use of HVDC and FACTS," *Proceedings of the IEEE*, vol. 88, pp. 235-245, 2000.

AUTHORS PROFILE

Nadimpally Anusha is pursuing MTech (Electrical Power Systems) in Avanthi Institute of Engineering and Technology, Telangana. He obtained B.Tech (Electrical and Electronics Engineering).

Mrs.E.Prasanna is working as an assistant professor in the department of EEE, Avanthi Institute of Engineering and Technology ,Telangana. She has more than 12 years of experience. She is a life member of the Indian Society for Technical Education.