International Journal of Electrical Engineering & Emerging Technology, Vol. 04, No. 02, DEC 2021, pp 46-50

Simulation Modeling of Modular Multilevel Converter

[a] Junaid Ali, [b] Dr. Abdul Hakeem Memon, [c] Dr. Zubair Ali Memon, [d] Maqsood Ahmed
[a] Mehran University of Engineering and Technology
Corresponding author e-mail: (engrjunaidali7@gmail.com)
[**Received on:** 15/11/2021 **Accepted on**: 26/11/2021 **Published on:** 04/12/2021]

Abstract From medium to high voltage applications one of the best topologies is the multi-level modular converter. Its output performance and quality depend upon the type of control used. Just like other conventional controls, the controller Nearest Level Modulation (NLM) is used for regulating MMC that generates N+1 output, where for per arm AC output voltage N denoting the number of sub-modules. This research work proposing an improved NLM control technique for the MMC that creates twice the levels compared to the traditional NLM approach.

***Keywords*—** **Power Quality, HVDC MMC, Improved NLM.**

I. Introduction

In 2003 Modular multilevel converter was introduced [1]. Since its inception, it is being mainly used in high power and voltage applications such as STATCOM, HVDC power transmission [2]–[5]. Fundamentally half-bridge configuration is used in the MMC submodules (SMs) structure [6]. Several SMs topologies and their control methods were developed for optimizing the cost without compromising on the power quality [7]–[10]. In [11]–[16] researchers have worked on the different approaches for MMC controls such as SHE, space vector control, PWM, and NLM. Keeping in view the benefit of low frequency for switching and N+1 levels, researchers have preferred the usage of SHE and NLM for step wave modulation. As compared to SHE, NLM is quite an attractive approach as it has several advantages over SHE such as natural voltage balancing, without involving complex math, easy implementation, due to these features NLM is preferred in HVDC applications [17]–[19]. For generating the pulses for all of the Upper and lower SMs in the NLM technique, referred arm voltages are given back to the modulator. Using nearest integer method, staircase waveform is produced by converting the reference sinusoidal arm potentials. After using the nearest integer procedure, the Submodules are being added and avoided through a normal sorting procedure subject to the level of voltage required, the arm voltage, and current polarity [20]–[21]. The literature review shows that to improve the power quality the number of levels is supposed to be increased. For increasing the number of levels, the SMs are also required to be increased. The increment in the no of SMs creates the hurdle for the designer as it requires more capacitors and switches which increase the complexity and cost of the MMC [22]. This paper offers a reformed NLM method (2N+1 levels) in which we improve the power quality by keeping the same number of SMs. As compared to the other improved methods, this method has benefits in relations of stress-free application and power quality. Researchers in [23] using the binary, trinary has reduced the MMC circuitry and improved the power quality, but it includes difficult calculation and their THD is greater as matched to our proposed modified NLM. The author of [26] offered increased level NLM with the decrease in the quantity of THD and SMs but their technique also contains as matched to our suggested modified NLM.

In this paper, the NLM approach is executed in LabVIEW and the MMC circuitry is developed in Multisim. Outcomes are gotten using the stage of LabVIEW Multisim co-simulation and NLM is compared with the modified NLM method.

II. Working Principle Of MMC

In Fig. 1 1-ϕ MMC circuit is shown. It contains inductor coupled upper-lower arms respectively has N-linked SMs in successions along with respectively one connected with two switches and a capacitor coupled across. Eq. 1 and 2 are obtained by using KVL in both upper and lower loop.

$$V = \frac{1}{2}\boldsymbol{V_{dc}} - \boldsymbol{V_U} - L\frac{di_U}{dt} \qquad (1)$$

$$V = \frac{1}{2}\boldsymbol{V_{dc}} + \boldsymbol{V_L} + L\frac{di_L}{dt} \qquad (2)$$

For output current Kirchhoff's current law (KCL) is being applied:

$$i = \boldsymbol{i_L} - \boldsymbol{i_U} \qquad (3)$$

The correspondent MMC circuit is being presented in Fig. 1(b). Now utilizing (1) and (2) the voltage yield will turn out to be

$$V = \frac{1}{2}(\boldsymbol{V_L} - \boldsymbol{V_U}) + \frac{1}{2}L\frac{di}{dt} \qquad (4)$$

Further from equation (3) equivalent alternating current (AC) voltage ($\boldsymbol{V_E}$) can be written as

$$\boldsymbol{V_E} = \frac{1}{2}(\boldsymbol{V_L} - \boldsymbol{V_U}) \qquad (5)$$

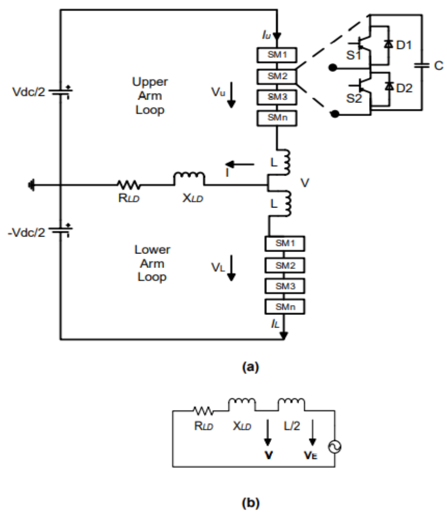

Fig 1. (a) MMC 1 Phase Circuit Structure (b) Equivalent Circuit

Usually, the AC correspondent voltage can be shown as

$$V_E^{ref} = \frac{m\boldsymbol{E_{dc}}}{2}\cos(\omega t) \quad (6)$$

Where:

- M ranging 0<m<1 is modulation index
- angular frequency is denoted by ω
- submodules(N number) are utilized in the circuit

By means of orthodox NLM method, the underneath equation is fulfilled on the direct current portion.

$$\boldsymbol{E_{dc}} = \boldsymbol{E_L} + \boldsymbol{E_U} \quad (7)$$

voltages taken as reference for upper-lower arm are

$$V_U^{ref} = \frac{V_{dc}}{2}[1 - m\cos(\omega t)] \quad (8)$$

$$V_L^{ref} = \frac{V_{dc}}{2}[1 + m\cos(\omega t)] \quad (9)$$

III. Conventional NLM Method

In NLM submodules number(N) to be added

$$N_U = round_{0.5}\frac{V_{dc}}{2V_d}(1 - m\cos(\omega t)) \quad (10)$$

$$N_L = round_{0.5}\frac{V_{dc}}{2V_d}(1 + m\cos(\omega t)) \quad (11)$$

Where:

- Vd is the instant SM capacitor voltage

By using round function real number is rounded to nearest integer .If the decimal fraction is < 0.5 then the function will be rounded to previous integer or else > 0.5 then function rounded to next integer.

A. Switching modes

In Fig 2. for understanding the switching states two cases [t1 to t2 & t2 to t3] are examined. In the initial instance [t1 to t2], supposing VL step equal to MVd then the upper and lower arm reference voltages can be shown as

$$\begin{cases} V_L^{ref} = (M + 0.5)V_d \\ V_U^{ref} = [(N - M - 1) + 0.5]V_d \end{cases} \quad (12)$$

$$V_E^{ref} = (M - 0.5N + 0.5)V_d \quad (13)$$

In the initial case [t1 to t2], arm voltages of step waveforms and alike internal voltage are stated as

$$\begin{cases} V_L^{step} = MV_d \\ V_U^{step} = (N - M)V_d \end{cases} \quad (14)$$

$$V_E^{step} = (M - 0.5N)V_d \quad (15)$$

In the second state [t2 to t3] reference of arm voltages and its alike internal voltage are stated as

$$\begin{cases} V_L^{ref} = [(M - 1) + 0.5]V_d \\ V_U^{ref} = [(N - M) + 0.5]V_d \end{cases} \quad (16)$$

$$V_E^{ref} = (M - 0.5N - 0.5)V_d \quad (17)$$

The arm voltages having step waves and equivalent inner voltages are shown as

$$\begin{cases} V_L^{step} = (M - 1)V_d \\ V_U^{step} = [(N - M) + 1]V_d \end{cases} \quad (18)$$

$$V_E^{step} = (M - 0.5N - 1)V_d \quad (19)$$

Now comparing (15) and (19), it can be seen that the height of step in V step isV_d. Since the positive and negative DC voltage limits are ±0.5Vdc, the max level in equivalent internal voltage is equivalent to V_{dc}/V_d +1.

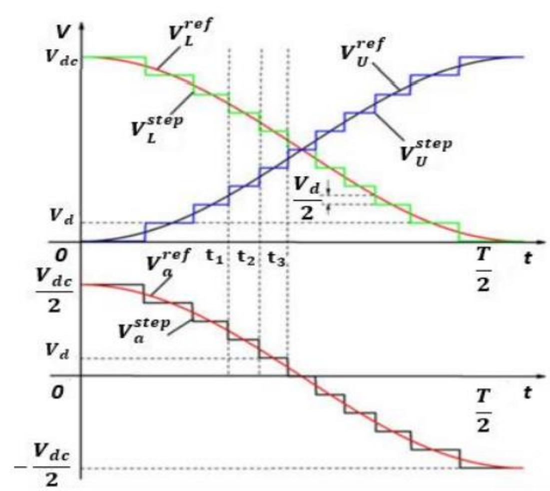

Fig 2. Switching arrangement of Conventional NLM

IV. PROPOSE MODIFIED NLM METHOD

The proposed method can be analyzed and executed by introducing the phase shift in any of the upper or lower arm of the circuit. Fig. 3 is showing the proposed modified NLM technique. In this we have added the phase shift in its lower arm. The reference and the staircase voltage waveform can be visualized through equation 20 and 21.

$$V_L^{ref} = \frac{V_d}{2}(1 + m\cos(\omega t + \beta)) \quad (20)$$

$$V_L^{step} = round_{0.5}\frac{V_d}{2}(1 + m\cos(\omega t + \beta)) \quad (21)$$

Using Fig. 4 we can calculate the value of β.

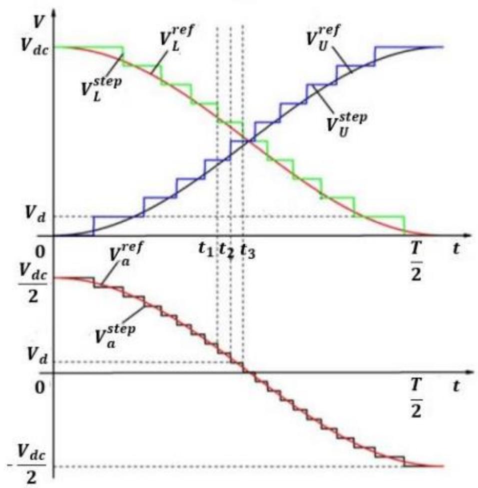

Fig 3. Modified NLM Method

For Execution of proposed co-simulation of NLM method, It is being implemented in the LabVIEW as depicted in the figure 4. In that algorithm we are feeding the voltage THD to the selection block in which the previous Total harmonic distortion iteration is existing. The phase shift is added or subtracted on the basis of THD. The increment in the phase is observed if present iteration THD is less than the preceding iteration or else decreased. Load deviation, momentary faults and transients will effect β angle. The value from 9.5 degrees to 11 degrees of β (phase shift) was observed as the ideal angle in amended NLM technique.

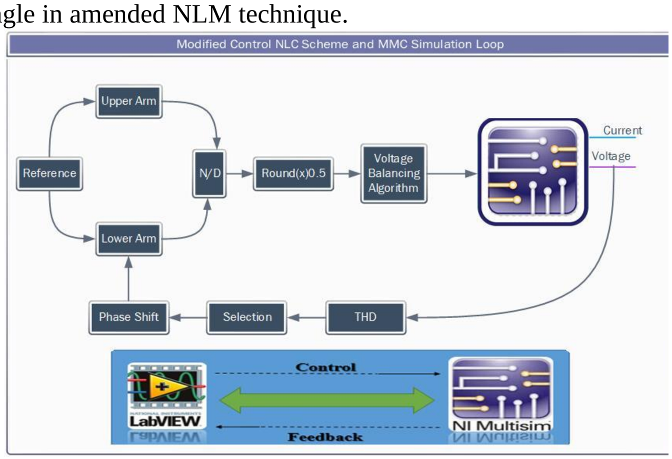

Fig 4. Proposed Modified NLM.

V. LABVIEW MULTISIM CO-SIMULATION

We have designed the conventional and modified NLM technique and got the co-simulation results for both and compared with each other. Table 1 is showing the parameters which are set for the designed three phase MMC. The results are also obtained for N+1 and 2N+1 levels.

TABLE. I
SIMULATION PARAMETERS

Item No.	System Parameters	Values
1	Vd	100V
2	Rated Frequency	50Hz
3	Line Arm Inductance	10mH
4	Line Inductance	100mH
5	Line resistance	1000 Ω

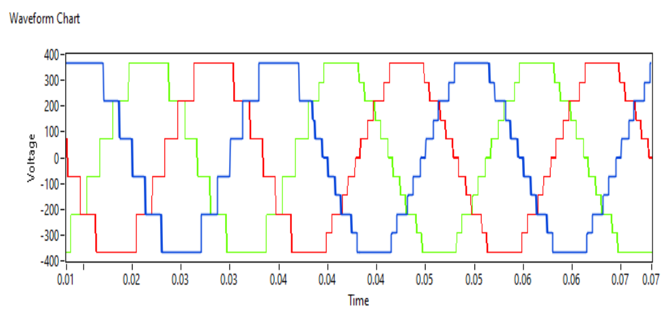

Fig 5. From 6 to 11 levels 3-phase output voltage waveforms.

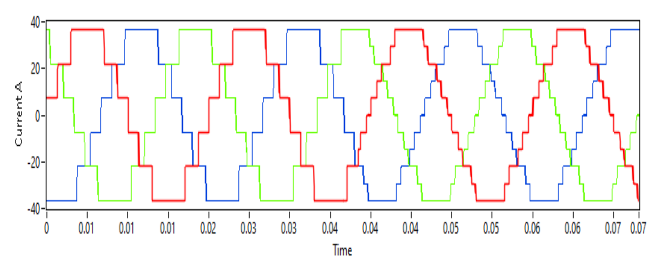

Fig 6. From 6 to 11 levels 3-phase output current waveforms.

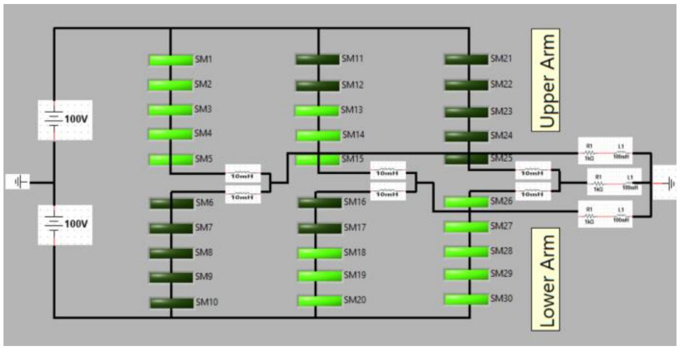

Fig 7. Visual Circuit Operation of Submodules

Through conventional NLM the current and voltage THD is *7.46%* and *12.10%* correspondingly for N+1 levels where N is equal to five. The improved NLM procedure is triggered at 0.04 sec and we get reduced Total harmonic distortion of current and its voltage output is as *4,35%* and *5.98%* correspondingly for N+1 level .

Fig 5 and Fig 6 are obtained by performing the co-simulation between LabVIEW Multisim. The comparative analysis of N+1 and 2N+1 is also depicted in the Table 2 which shows the efficiency of this modified NLM technique.

TABLE. 2
N+1 Comparison with 2N+1

Control Type	N	Voltage THD%	Current THD%
N+1	5	12.1	7.46
2N+1	5	5.98	4.35

VI. CONCLUSION

For higher value of THD, the applications of NLM control for MMC in the HVDC applications gets limited due to requirement of larger number of submodules, energy storing element termed as capacitors. Hence, this research work gives us a breakthrough in the shape of Modified NLM which improves the quality of power without increasing the number of submodules, capacitors. The effectiveness of improved NLM method is reflected through the Multisim LabVIEW Co-Simulation.

Thus we can conclude this research work in a way that our modified NLM method is capable of producing 2N+1 output voltage levels as compared to the conventional NLM method..

REFERENCES

[1] Lesnicar, Anton, and Rainer Marquardt. "An innovative modular multilevel converter topology suitable for a wide power range." In 2003 IEEE Bologna Power Tech Conference Proceedings, vol. 3, pp. 6-pp. IEEE, 2003.

[2] Ali, Saddaqat, Jahangir Badar, Faheem Akhter, Syed Sabir Hussain Bukhari, and Jong-Suk Ro. "Real-Time Controller Design Test Bench for High-Voltage Direct Current Modular Multilevel Converters." Applied Sciences 10, no. 17 (2020): 6004.

[3] Espinoza-B, Mauricio, Roberto Cárdenas, Jon Clare, Diego SotoSanchez, Matias Diaz, Enrique Espina, and Christoph M. Hackl. "An integrated converter and machine control system for MMC-based high-power drives." IEEE Transactions on Industrial Electronics 66, no. 3 (2018): 2343-2354.

[4] Bina, M. Tavakoli. "A transformerless medium-voltage STATCOM topology based on extended modular multilevel converters." IEEE Transactions on Power Electronics 26, no. 5 (2010): 1534-1545.

[5] Saad, H., J. Peralta, S. Dennetiere, J. Mahseredjian, J. Jatskevich, J. A. Martinez, A. Davoudi et al. "Dynamic averaged and simplified models for MMC-based HVDC transmission systems." IEEE Transactions on Power Delivery 28, no. 3 (2013): 1723-1730.

[6] Marzoughi, Alinaghi, Rolando Burgos, Dushan Boroyevich, and Yaosuo Xue. "Investigation and comparison of cascaded H-bridge and modular multilevel converter topologies for medium-voltage drive application." In IECON 2014-40th Annual Conference of the IEEE Industrial Electronics Society, pp. 1562-1568. IEEE, 2014.

[7] Qin, Jiangchao, Maryam Saeedifard, Andrew Rockhill, and Rui Zhou. "Hybrid design of modular multilevel converters for HVDC systems based on various submodule circuits." IEEE Transactions on Power Delivery 30, no. 1 (2014): 385-394.

[8] Lyu, Jing, Xu Cai, and Marta Molinas. "Optimal design of controller parameters for improving the stability of MMC-HVDC for wind farm integration." IEEE Journal of Emerging and Selected Topics in Power Electronics 6, no. 1 (2017): 40-53.

[9] Gnanarathna, Udana N., Aniruddha M. Gole, and Rohitha P. Jayasinghe. "Efficient modeling of modular multilevel HVDC converters (MMC) on electromagnetic transient simulation programs." IEEE Transactions on power delivery 26, no. 1 (2010): 316-324.

[10] Zhang, Lei, Yuntao Zou, Jicheng Yu, Jiangchao Qin, Vijay Vittal, George G. Karady, Di Shi, and Zhiwei Wang. "Modeling, control, and protection of modular multilevel converter-based multi-terminal HVDC systems: A review." CSEE Journal of Power and Energy Systems 3, no. 4 (2017): 340-352.

[11] Konstantinou, Georgios S., Mihai Ciobotaru, and Vassilios G. Agelidis. "Analysis of multi-carrier PWM methods for back-to-back HVDC systems based on modular multilevel converters." In IECON 2011-37th Annual Conference of the IEEE Industrial Electronics Society, pp. 4391-4396. IEEE, 2011.

[12] Konstantinou, Georgios, Mihai Ciobotaru, and Vassilios Agelidis. "Selective harmonic elimination pulse-width modulation of modular multilevel converters." IET Power Electronics 6, no. 1 (2013): 96- 107.

[13] Dekka, Apparao, Bin Wu, Navid R. Zargari, and Ricardo Lizana Fuentes. "A space-vector PWM-based voltage-balancing approach with reduced current sensors for

modular multilevel converter." IEEE Transactions on Industrial Electronics 63, no. 5 (2016): 2734-2745.
[14] Saeedifard, Maryam, and Reza Iravani. "Dynamic performance of a modular multilevel back-to-back HVDC system." IEEE Transactions on power delivery 25, no. 4 (2010): 2903-2912.
[15] Perez, Marcelo A., Steffen Bernet, Jose Rodriguez, Samir Kouro, and Ricardo Lizana. "Circuit topologies, modeling, control schemes, and applications of modular multilevel converters." IEEE transactions on power electronics 30, no. 1 (2014): 4-17.
[16] Li, Xiaoqian, Qiang Song, Wenhua Liu, and Jianguo Li. "Capacitor voltage balancing control by using carrier phase-shift modulation of modular multilevel converters." In Zhongguo Dianji Gongcheng Xuebao(Proceedings of the Chinese Society of Electrical Engineering), vol. 32, no. 9, pp. 49-55. Chinese Society for Electrical Engineering, 2012.
[17] Meshram, Prafullachandra M., and Vijay B. Borghate. "A simplified nearest level control (NLC) voltage balancing method for modular multilevel converter (MMC)." IEEE Transactions on Power Electronics 30, no. 1 (2014): 450-462.
[18] Son, Gum Tae, Hee-Jin Lee, Tae Sik Nam, Yong-Ho Chung, Uk-Hwa Lee, Seung-Taek Baek, Kyeon Hur, and Jung-Wook Park. "Design and control of a modular multilevel HVDC converter with redundant power modules for noninterruptible energy transfer." IEEE Transactions on Power Delivery 27, no. 3 (2012): 1611-1619.
[19] Debnath, Suman, Jiangchao Qin, Behrooz Bahrani, Maryam Saeedifard, and Peter Barbosa. "Operation, control, and applications of the modular multilevel converter: A review." IEEE transactions on power electronics 30, no. 1 (2014): 37-53
[20] Martinez-Rodrigo, Fernando, Dionisio Ramirez, Alexis B. ReyBoue, Santiago De Pablo, and Luis Carlos Herrero-de Lucas. "Modular multilevel converters: Control and applications." Energies 10, no. 11 (2017): 1709.
[21] Saad, Hani, Tarek Ould-Bachir, Jean Mahseredjian, Christian Dufour, Sébastien Dennetière, and Samuel Nguefeu. "Real-time simulation of MMCs using CPU and FPGA." IEEE Transactions on Power Electronics 30, no. 1 (2013): 259-267.
[22] Lin, Lei, Yizhe Lin, Zhen He, Yu Chen, Jiabing Hu, and Wuhua Li. "Improved nearest-level modulation for a modular multilevel converter with a lower submodule number." IEEE Transactions on Power Electronics 31, no. 8 (2016): 5369-5377.
[23] Alexander, Albert, and Manigandan Thathan. "Modelling and analysis of modular multilevel converter for solar photovoltaic applications to improve power quality." IET renewable power Generation 9, no. 1 (2014): 78-88.
[24] Zhao, Wenjian, Kun Yang, and Guozhu Chen. "An improved nearest-level-modulation of modular multilevel converter— STATCOM." In 2015 IEEE 11th International Conference on Power Electronics and Drive Systems, pp. 219-223. IEEE, 2015.
[25] Liu, Qi, Alian Chen, Chunshui Du, and Chenghui Zhang. "A modified nearest-level modulation method for modular multilevel converter with fewer submodules." In 2017 Chinese Automation Congress (CAC), pp. 6551-6556. IEEE, 2017.
[26] Hu, Pengfei, and Daozhuo Jiang. "A level-increased nearest level modulation method for modular multilevel converters." IEEE Transactions on Power Electronics 30, no. 4 (2014): 1836-1842.
[27] Gebreel, Abd Almula, and Longya Xu. "Power quality and total harmonic distortion response for MMC with increasing arm inductance based on closed loop-needless PID controller." Electric Power Systems Research 133 (2016): 281-291.
[28] Mishra, Prabhat, and Mukesh M. Bhesaniya. "Comparison of total harmonic distortion of modular multilevel converter and parallel hybrid modular multilevel converter." In 2018 2nd International Conference on Trends in Electronics and Informatics (ICOEI), pp. 890-894. IEEE, 2018.
[29] Shojaei, A., and G. Joos. "An improved modulation scheme for harmonic distortion reduction in modular multilevel converter." In 2012 IEEE Power and Energy Society General Meeting, pp. 1-7. IEEE, 2012.
[30] Deng, Yi, Maryam Saeedifard, and Ronald G. Harley. "An improved nearest-level modulation method for the modular multilevel converter." In 2015 IEEE Applied Power Electronics Conference and Exposition (APEC), pp. 1595-1600. IEEE, 2015