

Innovative Control Strategy for Renewable Energy Sources Integration using Five-Level Multilevel Inverter

Pramod Ghutte¹, Swapnil Gadgune², Sushant Kamble³, Mandar Dongare⁴ and Suhel Shaikh⁵

^{1-2,4-5}Dept. of Electrical Engg., PVPIT, Budhgaon, Sangli, MH, India

Email: pramod07sagar@gmail.com, swapnilgadgune, mandar1450, suhelshaikh7}@gmail.com

³Dept. of Electrical Engg., WCE, Sangli, Sangli, MH, India

Email: sushant1win

Abstract— This paper introduces a novel control strategy for a five-level multilevel inverter (MLI) aimed at integrating multiple renewable energy sources (RES) into the grid. The suggested method preserves a unity power factor while guaranteeing accurate power injection in line with reference values. Utilizing the advantages of MLI, such as reduced AC current distortion and decreased dv/dt stresses, the approach shows effectiveness in power integration. MATLAB/Simulink simulations validate the proposed control scheme, highlighting its potential to effectively integrate RES into the power grid.

Index Terms— Multi Level Inverter (MLI), Renewable Energy Source (RES), Synchronous Reference Frame (SRF), Phase Shifted Carrier based Sinusoidal PWM (PS-PWM)..

I. INTRODUCTION

The increasing importance of renewable energy sources (RES) in the global energy landscape is undeniable, driven by environmental concerns, depleting fossil fuel resources, and the urgent need to mitigate climate change [1]. As the world transitions towards sustainable energy solutions, the integration of RES into existing power grids becomes a critical focal point. This paradigm shift is reflected in the rapid growth of renewable energy installations across the globe. Wind, solar, and other clean energy technologies are experiencing unprecedented adoption rates, necessitating innovative approaches to efficiently harness and incorporate their power into the grid [2].

Various inverter topologies play a crucial role in addressing the challenges associated with the integration of renewable energy sources (RES) into the power grid. While traditional two-level inverters have served their purpose, they exhibit limitations such as higher harmonic content and restricted capacity for handling multiple RES simultaneously. Multilevel inverters (MLIs) emerge as a more versatile solution, capable of accommodating higher voltages, minimizing dv/dt stresses, and producing fewer harmonics [3]. Within the realm of MLIs, three major types stand out: diode-clamped, capacitor-clamped, and cascade H-bridge inverters [4]. This paper zeroes in on the cascade H-bridge topology for RES integration due to its distinctive advantages. All of the capacitors used in flying capacitor clamped MLI must have the same rating, which can make them costly and large in size. Unlike diode-clamped MLIs, the cascade H-bridge configuration eliminates the need for a DC voltage balancing circuit.

Additionally, the cascade MLI approach treats each renewable source as a separate DC source, allowing for the generation of appropriate voltage levels even in the presence of intrinsic characteristic mismatches among RESs. This strategic use of cascade H-bridge inverters holds promise for overcoming challenges associated with RES integration and enhancing the overall efficiency of renewable energy systems in the grid [5], [6].

In this paper a novel control technique to operate the five-level cascaded H-Bridge MLI is proposed. The active and reactive power is controlled using PI-controller. The Phase shifted carrier based Sinusoidal PWM technique is used for pulse generation. The simulation is prepared using MATLAB/Simulink software. and results are presented. It shows effectiveness of the proposed technique.

II. CASCADED H-BRIDGE MLI

A three-phase structure of a 5-level cascaded inverter is shown in figure 1. Each Separate DC Source (SDCS) is connected to a single-phase full-bridge, also called as H-bridge inverter. The DC sources are representing output of RES sources in DC form. Therefore, this configuration is able to feed energy from six different energy sources to the grid. Each inverter level can generate three different voltage outputs, $+V_{dc}$, 0, and $-V_{dc}$ by connecting the dc source to the ac output by switching ON or OFF switches S_1 - S_4 . When switches S_1 and S_2 are turned on, we obtain $+V_{dc}$, whereas $-V_{dc}$ can be obtained by turning on switches S_3 and S_4 . When switches S_1 and S_4 or S_3 and S_2 are ON, then output voltage is 0. The resulting phase voltage is synthesized by the addition of the voltages generated by the different full bridge inverter levels. The resulting output ac voltage swings from $[(2V)_{dc}]$ to $-[(2V)_{dc}]$ with five levels, and the staircase waveform is nearly sinusoidal. The number of output phase voltage levels $m = 2s+1$, where s is the number of Separate dc sources. For example, if there are 2 Separate DC Sources, then the phase voltage waveform is 5 steps staircase [7].

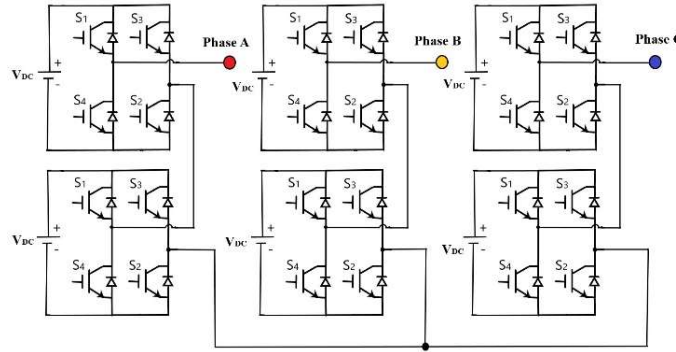


Figure 1. Three-Phase Five-Level Cascaded H-Bridge MLI

III. CONTROL STRATEGY

The cascaded MLI is feeding energy to the grid. The resistive load is getting part of the required energy from the MLI. The control strategy of Cascade MLI is shown in figure 2. The three phase voltages and currents are measured to calculate active and reactive power as shown below.

$$P = V_a i_a + V_b i_b + V_c i_c \quad (1)$$

$$Q = \frac{1}{\sqrt{3}} [(V_b - V_c) i_a + (V_c - V_a) i_b + (V_a - V_b) i_c] \quad (2)$$

The calculated active and reactive power are compared against respective reference values. Reference reactive power is set equal to zero to have unity power factor operation. The respective errors are given to PI controllers. The output of PI controller of active power loop is direct axis component (I_d^*) whereas reactive power loop gives quadrature axis component (I_q^*) of current.

The power system is considered to be balanced. Therefore, zero sequence component is absent. The calculated $dq0$ components are transformed into three phase reference currents I_{abc}^* as given in equation below [8].

$$\begin{bmatrix} I_a^* \\ I_b^* \\ I_c^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} I_d^* \\ I_q^* \end{bmatrix} \quad (3)$$

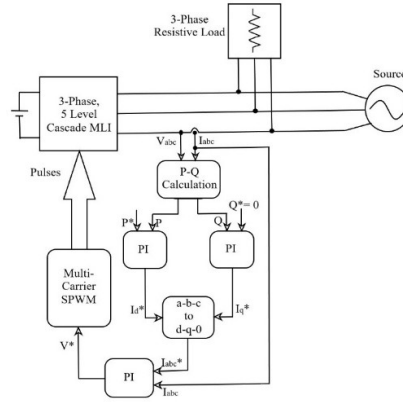


Figure 2. Control Strategy

The actual ac current I_{abc} is compared against reference current I_{abc}^* . Then error is given to outer loop PI controller. It will calculate modulating signal V^* . The parameters of this PI controller are chosen in such a way to avoid overmodulation. The modulating signal is used to calculate pulses, which will drive the MLI switches.

IV. PULSE GENERATION

The phase-shifted carrier based sinusoidal PWM approach is used to generate pulses for the cascaded H-Bridge multilevel inverter as shown in figure 3. The upper switch of the left leg of the upper H-Bridge is controlled by gating pulses generated by the carrier signal seen in the figure, whereas the upper switch of the right leg of the upper H-Bridge is controlled by an inverted carrier signal. In a similar way, lower H-Bridge is controlled by a carrier signal with a 90° phase shift [9], [10].

V. SIMULATION RESULTS

The simulation of proposed control technique for cascaded H-bridge MLI is prepared using MATLAB/Simulink software. The sample time is taken equal to 50×10^{-6} sec. The values of the parameters used in the simulation are given in the Table-I below.

TABLE I. CASCADED MLI PARAMETERS

Parameters	Value
AC Source Line Voltage	280 V _{RMS} , 50 Hz
DC Source Voltage	350 V
Carrier Frequency	5 kHz
Resistive Load	25 kW

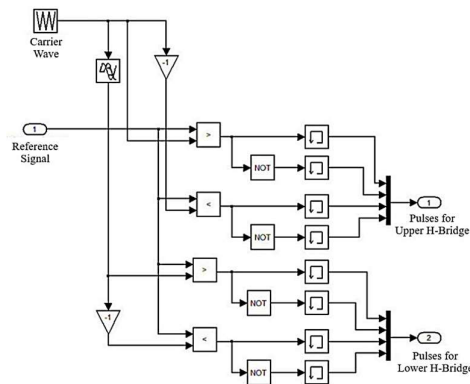


Figure 3. Phase shifted carrier based Sinusoidal PWM technique

Figure 4 (a) shows injected power is exactly tracking the reference active power. The reactive power is also maintained equal to zero as depicted in figure 4 (b). The current is maintained in phase of the voltage waveform as shown in figure 5. Response to the step change in reference active power is shown in figure 6. Initially, the MLI is set to inject active power of 5000 W, after 2 sec reference is changed to 8000 W. The rise time in this case is 0.015 sec with no overshoot. After 4 sec the reference is reduced to 6000 W and rise time noted equal to 0.014 sec with no undershoot. The %THD of AC side current is found to be 1.49% as shown in figure 7.

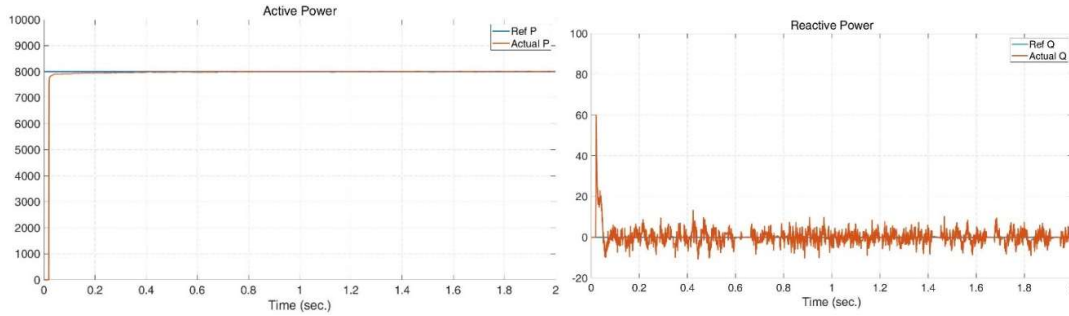


Figure 4. Response of Cascaded H- Bridge MLI (a) Active Power (b) Reactive Power

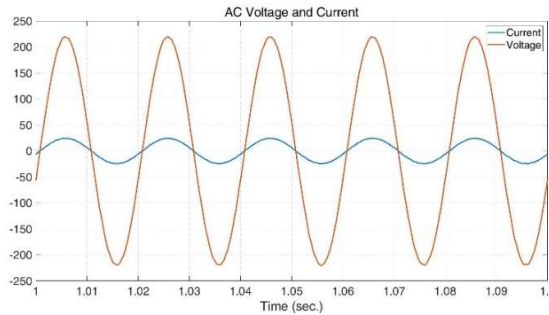


Figure 5. Current and Voltage Waveform

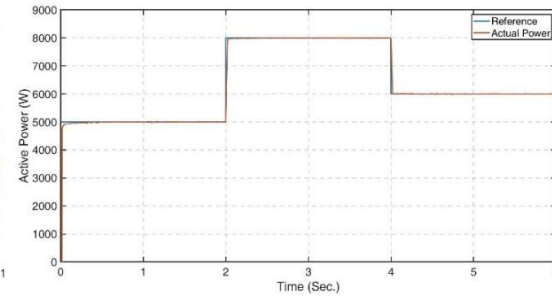


Figure 6. Response to Step Change in Reference Active Power

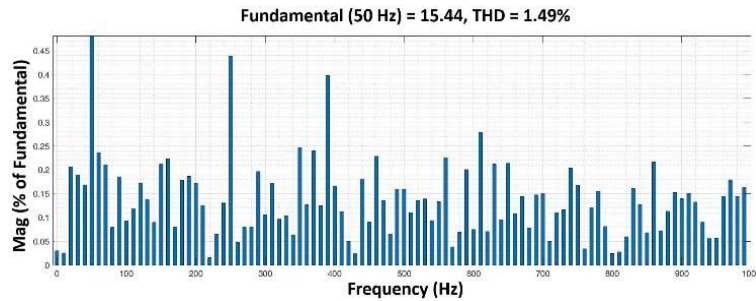


Figure 7. %THD of Source Current

VI. CONCLUSIONS

The 5-level Cascaded H-Bridge MLI is controlled to feed required power to the grid. The injected active power curve exactly tracks the command without any offset. The step response in active power shows that there is no overshoot or undershoot and rise time is also very small. The reactive power is maintained zero giving unity power factor operation. The %THD is also below the limit set by IEEE standards. The results are presented, which validates the effectiveness of the proposed technique.

REFERENCES

- [1] D. Gielen, F. Boshell, D. Saygin, M. D. Bazilian, N. Wagner, and R. Gorini, "The role of renewable energy in the global energy transformation," *Energy Strategy Rev.*, vol. 24, pp. 38–50, Apr. 2019, doi: 10.1016/j.esr.2019.01.006.

- [2] E. Martinot, "Grid Integration of Renewable Energy: Flexibility, Innovation, and Experience," *Annu. Rev. Environ. Resour.*, vol. 41, no. 1, pp. 223–251, 2016, doi: 10.1146/annurev-environ-110615-085725.
- [3] R. Mali, N. Adam, A. Satpaise, and A. P. Vaidya, "Performance Comparison of Two-Level Inverter with Classical Multilevel Inverter Topologies," in 2019 IEEE International Conference on Electrical, Computer and Communication Technologies (ICECCT), Feb. 2019, pp. 1–7. doi: 10.1109/ICECCT.2019.8869115.
- [4] E. Kabalci, *Multilevel Inverters: Introduction and Emergent Topologies*. Academic Press, 2021.
- [5] A. Gaikwad and P. A. Arbune, "Study of cascaded H-Bridge multilevel inverter," in 2016 International Conference on Automatic Control and Dynamic Optimization Techniques (ICACDOT), Sep. 2016, pp. 179–182. doi: 10.1109/ICACDOT.2016.7877574.
- [6] K. T. Maheswari, R. Bharanikumar, V. Arjun, R. Amrith, and M. Bhuvanesh, "A comprehensive review on cascaded H-bridge multilevel inverter for medium voltage high power applications," *Mater. Today, Proc.*, vol. 45, pp. 2666–2670, Jan. 2021, doi: 10.1016/j.matpr.2020.11.519.
- [7] S. Khomfoi, L. M. Tolbert, "Multilevel Power Converters," *Power Electronics Handbook*, 3rd Edition, Elsevier, 2011, ISBN 978-0-12-382036-5, Chapter 17, pp. 455–486.
- [8] S. Y. Kamble, S. V. Ambesange, and M. M. Waware, "Capacitor voltage regulation in Shunt Active Power Filter using Sliding mode controller," in 2013 IEEE International Conference on Control Applications (CCA), Aug. 2013, pp. 1135–1140. doi: 10.1109/CCA.2013.6662904.
- [9] P. Chaturvedi, "Chapter Three - Conventional Multilevel Inverter: Topologies and Control Strategies," in *Modeling and Control of Power Electronics Converter System for Power Quality Improvements*, S. K. Dwivedi, S. Jain, K. K. Gupta, and P. Chaturvedi, Eds., Academic Press, 2018, pp. 85–120. doi: 10.1016/B978-0-12-814568-5.00003-X.
- [10] S. Y. Gadgune, P. T. Jadhav, L. R. Chaudhary, and M. M. Waware, "Implementation of shunt APF based on Diode Clamped and Cascaded H-bridge multilevel inverter," in 2015 IEEE International Conference on Electrical, Computer and Communication Technologies (ICECCT), Mar. 2015, pp. 1–7. doi: 10.1109/ICECCT.2015.7225961.