



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

IJIRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 12, Issue 1, January 2023

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 8.118

9940 572 462

6381 907 438

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Power Quality Improvement for Symmetrical Cascaded Multilevel Converter

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ABSTRACT: In this paper, the proposed Pulse Modulated Switching Cascaded H-bridge Multilevel Inverter (PM-SCHM) can be utilized for the reduction of Total Harmonic Distortion (THD). The proposed PM-SCHM scheme consists of a multi-level inverter arranged in an H-bridge Cascaded manner. To compensate harmonic current magnitude in opposite direction Shunt Active Power Filter (APF) is used. A pulse modulation scheme is applied to the proposed PM-SCHM scheme for the arrangement of components using Linear Quadratic Regulator (LQR). The constructed LQR scheme utilizes a load for compensation with source voltage. This research focused on 5th order harmonics with a fundamental frequency of 50Hz. The comparative analysis of simulation results exhibited that the proposed Pulse Modulated Switching based Cascaded H- bridge Multilevel Inverter PM-SCHM scheme exhibits significant performance rather than the conventional technique.

KEYWORDS: Multilevel Inverter, Total Harmonic Distortion, Shunt Active power filter, Linear Quadratic Regulator.

I. INTRODUCTION

In high power electrical, output waveform incorporates harmonic content which needs to be reduced to minimize distortion within the grid and need to reach maximum energy efficiency[1]. On those electrical applications, the presence of thermal loss limits the maximum switching frequency to a few hundred hertz. To withstand maximum switching in electrical applications multilevel converters are utilized[2]. Research has been conducted for various multilevel converter topology which exhibits significant performance for high power applications [3]. Additionally, it is necessary to develop appropriate modulation and filtering system with grid codes at the point of common coupling. Usually, grid codes exhibit limited harmonic capability of 50th of its Total Harmonic Distortion (THD). In a grid system, passive filters are utilized for the reduction of harmonic distortion in grids due to complex structure and cost.

Several existing strategies exhibit effective performance with the construction of a local or global control model for harmonic or voltage unbalance through compensation mechanism. Nevertheless, a vast range of restrictions is applied for those methods due to difficulty in higher penetration and decentralized distribution of sources which causes serious harmonic distortion and voltage unbalance in a distributed network. The local control models in a distributed system do not provide an improved functionality of nodes due to network structure and distribution of propagation scheme [4]. Further, system parameters such as source distribution and intensity and line impedance require a control model through global optimization for harmonic distortion or voltage unbalance. Due to the penetration of massive signal generation and loads in power electronics results in complicated and changeable environment factor in a distributed network environment. The network intensity and distribution are difficult for identification those can be determined through a randomness of the Distributed Grid (DG) output power and uncertainty of location in electronic loads [5]. Meanwhile, errors in-line parameters are observed with an increase in network expansion, change in a branch, and cable aging [6].

In hybrid asymmetrical cascade inverter topology, the main concept is obtaining better inverter performance with the concept of hybridizing with the inclusion of various cells and switches. In a hybrid inverter, a combination of slow switches, features of high blocking voltage, and relative conduction losses are obtained for better equivalent switches that exhibit faster switching capability, minimal conduction losses, and minimal switching losses [7]. For the operation of high-voltage cells with the minimum switching frequency, the concept of Pulse Width Modulation (PWM) is utilized.

Through designing and controlling inverter topology, it is possible to modulate all pairs of low-voltage cells with adjacent level switching characteristics [8]. The concept of that multi-level inverter topology is the reduction of

switching losses rather than optimized and generalized single-phase inverters with the introduction of optimized transition with switching - state space[9], in three-phase inverters concept of modulation domain, is evolved[10]. The reduction of THD in multi-inverter network topology with a reduction of switching in the network. The section presented existing literature focused on improving the performance of multilevel inverter for the application of high-power applications. Researcher [11], suggested a topology with consideration of basic units arranged in cascade order. The designed topology consists of both unidirectional and bidirectional switches with two dc voltage sources. The constructed network topology includes two parts such as level-generation and polarity generation parts. In the level-generation part, two power switches are included those are arranged in the unidirectional platform and common emitter configuration consists of bidirectional blocking switches. In traditional network topology, several isolated DC voltage sources are equal to several power switches for reduction of voltage drop, topology volume, and cost compared with CHB multilevel inverter topology network.

Another technique developed in[12], proposed PM-SCHM two separate parts level generation and polarity generation. The circuit configuration of MLM multilevel inverter with four dc input sources. This topology can reduce the number of dc voltage sources, switches, IGBTs, and power diodes as the number of output voltage levels increases. The disadvantage of this topology is that it cannot operate with an asymmetric configuration. This topology uses applications that require high power quality and applications that have considerable numbers of dc voltage sources. In research conducted by [13] developed a cross-connected source-based multilevel inverter (CCSMLI), with the inclusion of two isolated input sources located in each cell. The constructed DC sources are interconnected with the inclusion of higher pole terminal with the upstream source connected with lower pole terminal of source acting in downstream with switches and vice versa. This developed topology consists of a minimal number of switches compared with traditional MLI. Further, this topology is effective for available isolated DC sources.

In [14], focused on the location of the space vector in multilevel inverter arranged in fractal structure, with the inclusion of the SVPWM algorithm. The proposed PM-SCHM approach focused on sector identification without any lookup tables. In [15], constructed a novel MLI as Mokhberdorran Topology. The constructed network topology consists of two symmetric DC voltage sources, six switches, and eight diodes. The developed network topology exhibits significant advantages rather than traditional MLI topologies. From the analysis, it is observed that Mokhberdorran topology exhibits an effective choice of multilevel inverters for high power application performance scenarios. In [16] developed a new topology defined as "reversing voltage" MLI (RV-MLI) topology. This designed topology consists of two stages for the effective generation of the output voltage. In level-generation stages based on the positive polarity, levels are generated while the polarity-generation stage produces alternate voltage for the network[17 - 19]. Those topologies are duplicated based on the number of levels provided in the middle stage. Therefore, it can be suitable for three-phase applications for redundant and flexible sequence switching. Those topologies are not able to perform effectively for various DC source magnitudes with additive and subtractive combination of DC sources in the network [20].

This paper proposed a PM-SCHM scheme for the reduction of THD in high power electronic applications with improved efficiency. The proposed PM-SCHM scheme utilizes Pulse Switching Modulation Scheme integrated with Shunt Hybrid Filters (SHF). Through the incorporation of SHF frequency loss of the electrical network can be reduced. Further to reduce harmonics in the electrical network LQR is used which consists of load, phase voltage, and controller for effective maintenance of voltage flow within the circuit. The designed 3-phase circuit is arranged for the reduction of THD. The simulation of the proposed PM-SCHM scheme is comparatively examined with the existing approach stated that the proposed scheme provides significant performance rather than the conventional technique.

The organization of the paper is as follows: section 1 provides a general introduction and gives a detailed survey of existing modulation, harmonic distortion techniques. Then, in section 2 proposed PM-SCHM methodology is explained with some equations. Section 3 gives a detailed analysis of some parameters. Finally, the paper is concluded in section 4.

II. PROPOSED PM-SCHM FOR REDUCTION OF THD

This paper, presented about Pulse modulated switching based H-bridge multilevel inverter with Linear Quadratic Regulator for reduction of THD in the network. In Fig.1, presented about the flow of proposed PM-SCHM approach which includes diodes, capacitors, and switches. The constructed multilevel cascade inverter integrates several voltage levels and generates a sinusoidal voltage waveform. For the constructed inverter single-phase full-bridge is utilized for the generation of phases. A single-phase multilevel cascade Inverter topology is considered an essential component for the identification of phase legs located in a series-chain of H-bridge inverter, which generates various output voltage waveforms.

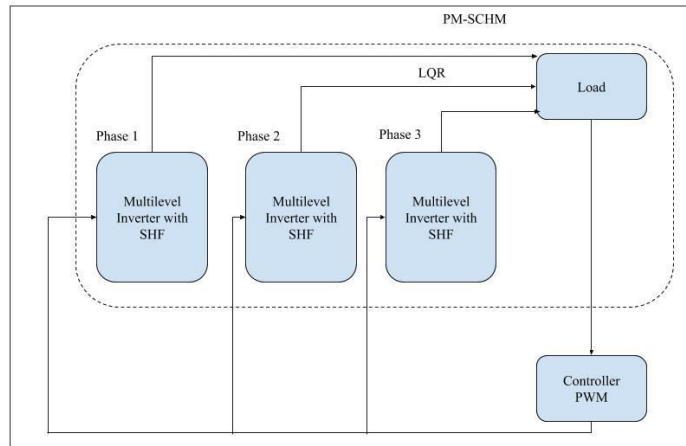


Fig.1. An overview of proposed PM-SCHM architecture

Those characteristics are difficult to achieve in other voltage source control topologies with DC link. In this topology, power conversion cells are arranged in series, hence voltage and power level can be measured easily. Within full-bridge inverter, DC link supply is provided individually, and this can be achieved through diode rectifiers without any single-phase transformer. The topology of the converter is arranged based on the series connection with a single-phase inverter with separate DC sources resulted in the synthesis of phase voltage with the addition of voltage generated by various power conversion cells.

2.1 Load balancing using Shunt Hybrid power filter

In Fig.2, illustrated about shunt APF scheme applied for three-phase four-wire system. In the system, load is provided in unbalanced linear and balanced linear voltage sources. The below equation (1), (2) and (3) provides the current measurement for both balanced and unbalanced load condition in the network.

$$i_{fa}^*(t) = i_{la}(t) - \frac{2(P_T + P_{loss})}{U_T} \sin(\omega t + \phi_{a1}) \quad (1)$$

$$i_{fb}^*(t) = i_{lb}(t) - \frac{2(P_T + P_{loss})}{U_T} \sin(\omega t + \phi_{a1} - \frac{2\pi}{3}) \quad (2)$$

$$i_{fc}^*(t) = i_{lc}(t) - \frac{2(P_T + P_{loss})}{U_T} \sin(\omega t + \phi_{a1} + \frac{2\pi}{3}) \quad (3)$$

where $i_{fk}^*(t)$ is represented as filtering current for phase k, $i_{lk}(t)$ is the phase of line current k. The developed system utilizes both balanced and unbalanced load conditions, hence load current incorporates both linear unbalanced load current and load current of rectifier; the subscript k represents the phases a, b or c, respectively. The total active power delivered to the load is denoted as P_T ; source voltage u_k with peak value sum is represented as U_T , load phase voltage components with phase angle a_1 has phase of a, and x is denoted as angular speed fundamental frequency 'f' as 60Hz.

After the generation of reference current, it is applied to the hysteresis-band current controller for a control signal from the voltage source inverter (VSI) and performs actual current filtering that applied to APF electrical system. In the designed circuit C1 and D1 utilized for energy storage and applied to capacitors for where voltage fluctuates instantaneously due to the presence of harmonics. In the electrical system, at the terminals of inverter constant DC voltage U_{dc} is applied. The loss generated by switching and capacitor variation in voltage needs to be applied to the source, a controller power loss P_{loss} are summed at P_r . In the designed compensation scheme, harmonic cancellation and reactive power are not included in the Shunt APF compensation mechanism. Through these assumptions shunt APF or reference current generator are not utilized by the control algorithm. The shunt APF suggest to include the use of capacitor bank with with the advanced the load component, and hence the load current is sense with the site of the shunt capacitor bank.

The proposed PM-SCHM multilevel inverter utilizes the LQR method for controlling complex electrical systems with effective network performance. The designed PWM scheme utilizes an optimal controller with a minimization of the cost function. The cost function utilized for the proposed PM-SCHM multilevel inverter utilizes two matrices such as Q and R. Further, the designed network consists of weight assigned with state vector and input system. In this research, to reduce harmonic distortion LQR switching controller is designed for control signal



generation of inverter voltage source applied for shunt APF and SHF compensation scheme. The functionality of the proposed PM-SCHM LQR-switching controller involved in the improvement of harmonic ripple current in the electrical system with SHF compensation.

2.2 Pulse-switching controller with LQR method

In an electrical system, Pulse-based switching controller is constructed for optimal controlling of signal for reduction of performance index using the following equation (4):

$$J = \int_0^\infty \{ (w - w_{ref})^T Q (w - w_{ref}) + u^T R u \} dt \tag{4}$$

In the above equation (4), the state vector is denoted as w and wref are represented as the desired reference of state vector; a semi-definite matrix symmetric or Hermitian matrix is denoted as Q and symmetric positive definite matrix as R.

In some scenarios, R is in scalar form, and sets are included in network control. With the use of optimal control law stated in equation (5), the cost function is reduced through the feedback control form. In the below equation (5) T is the network transpose vector and m is denoted as an optimal control law.

$$m = -K(w - w_{ref}) \tag{5}$$

With gain matrix K solution is obtained by steady-state Riccati equation with suitable gain matrix and switching control.

$$m = -hys(K(w - w_{ref})) \tag{6}$$

In above equation (6), the term hys is represented as follows equation (7) and equation (8) by,

$$\text{if } K(w - w_{ref}) > \frac{\Delta_i}{2} \text{ then } hys(K(w - w_{ref})) = 1 \tag{7}$$

$$\text{elseif } K(w - w_{ref}) < \frac{\Delta_i}{2} \text{ then } hys(K(w - w_{ref})) = -1 \tag{8}$$

Based on the above equation the proposed PM-SCHM model is utilized for switching and tracking control and selection of Di involved in switching frequency concerning reference tracking. The proposed PM-SCHM equivalent circuit incorporates hybrid filter compensation with the inclusion of both linear and nonlinear loads arranged in the RL series circuit arrangement of the load. In the below equation (9) and equation (10) state vector x related to state-space equation are presented.

$$x = [i_1 \ i_2 \ i_3 \ i_4]^T \tag{9}$$

$$\dot{x} = \begin{bmatrix} -\frac{R_s}{L_s} & 0 & 0 & -\frac{1}{L_s} \\ 0 & -\frac{R_f}{L_f} & 0 & -\frac{1}{L_f} \\ 0 & 0 & -\frac{R_{eq}}{L_{eq}} & -\frac{1}{L_{eq}} \\ \frac{1}{C_f} & \frac{1}{C_f} & -\frac{1}{C_f} & 0 \end{bmatrix} x + \begin{bmatrix} \frac{1}{L_s} \\ 0 \\ 0 \\ 0 \end{bmatrix} u_s + \begin{bmatrix} 0 \\ \frac{V_{dc}}{L_s} \\ 0 \\ 0 \end{bmatrix} m \tag{10}$$

For estimation equation (11) and equation (12), the state vector x is converter into new state vector w, which is based on local variables and control variables with filtering current cf and capacitor current as ic, the capacitor voltage terminal as UC and load current il.

$$w = \begin{bmatrix} i_f \\ i_c \\ u_c \\ i_l \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 1 & 1 & -1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \\ u_c \end{bmatrix} = V_x \tag{11}$$

$$A = \begin{bmatrix} -\frac{R_f}{L_f} & 0 & -\frac{1}{L_f} & 0 \\ \frac{R_s}{L_s} - \frac{R_f}{L_f} & -\frac{R_f}{L_s} & -\frac{1}{L_s} - \frac{1}{L_f} - \frac{1}{L_{eq}} & -\frac{R_s}{L_s} + \frac{R_f}{L_f} \\ 0 & \frac{1}{C_f} & 0 & 0 \\ 0 & 0 & \frac{1}{L_{eq}} & -\frac{R_{eq}}{L_{eq}} \end{bmatrix}; \gamma_1 = \begin{bmatrix} 0 \\ \frac{1}{L_s} \\ 0 \\ 0 \end{bmatrix}; \gamma_2 = \begin{bmatrix} \frac{U_{dc}}{L_f} \\ \frac{U_{dc}}{L_f} \\ 0 \\ 0 \end{bmatrix} \tag{12}$$

Based on the control law presented in equation (12), it is assumed that the network involved in full control over m for pulse switching and switching controller involved in linear multiple state combinations illustrated in Fig 3(c).

Through the utilization of the LQR switching controller current complexity of the network is reduced with the generation of inverter switching commands those are similar to hysteresis controller band current, this has been utilized in shunt active power filter applications. However, the challenges related to weighting matrices Q are selected for

appropriate network performance. Mostly, controller states are presented by the weighted matrix Q and select appropriate value R for system control effect for achieving regulator convergence finite time. Alternatively, tuning decisions of weighted matrices are examined with a system step response for measuring steady-state of controller Q and R with the application of LQR design. After, the inclusion of LQR algorithm feedback matrices is estimated for measuring changes in the circuit and load circuit.

III. RESULT AND DISCUSSION

In this section, presented about results obtained for the proposed PM-SCHM pulse width modulation scheme with H-bridge cascaded network. The analysis of the proposed PM-SCHM model illustrated that it consists of three components such as (i) Pulse Width Modulation scheme, (ii) Shunt Hybrid Filter (SHF), and (iii) Linear Quadratic Regulator. The simulation parameters are listed in table 1.

Table 1. Simulation Setting for PM-SCHM

Parameters	Values
Simulation Software	MATLAB 2019a
RAM memory	4 GB
Processor	Intel core i7 processor
Modulation	Pulse Width Modulation
Input Voltage	300V
Phase Voltage	350V

3.1 Simulation Analysis

The performance of the proposed PM-SCHM system involved in PWM voltage measurement, phase voltage, the line-to-line voltage, and Total Harmonic Distortion (THD). The PM-SCHM involved in the construction of 7-levels with regulator design for measuring line to line voltage, phase voltage, and THD. In Fig 4, input voltage applied for proposed PM - SCHM scheme is presented.

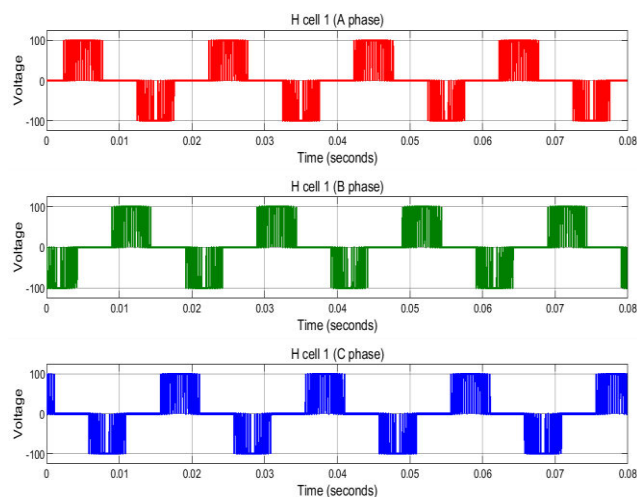


Fig. 2. Measurement of Voltage Using the Proposed PM-SCHM

The proposed PM-SCHM uses a pulse modulation scheme with the inclusion of a 3-phase electrical circuit arranged in 7-levels. Through the application of Pulse switching the load applied to the system converts an analog signal into a step signal. In Fig 4 voltage measured for constructed 3-phase circuit network are presented concerning A phase, B phase, and C phase. From Fig 2, it is observed that voltage all 3-phases utilizes a voltage value of 100 volts for the time period of 0 to 0.08 seconds. In three-phase electrical circuit phase voltage and phase, current exhibits significant performance for transmission of a signal from source to voltage. Generally, phase voltage is represented as a voltage measured between single components located in the three-phase circuit source or load. In Fig 4 voltage measured is 100 volts in square shape waveform.



3.2 Measurement of Total Harmonic Distortion

To understand the THD related to the phase change between carrier signals, the V-I activation signal graph was analyzed. Also, the conduction and short-circuit sequence were established for each instant of turning ON and OFF the V-I converter. In the proposed PM-SCHM, aimed to minimize the THD of the electrical network. To evaluate the performance of proposed PM-SCHM scheme for multi-level inverter THD of input signal and THD in line voltage are measured those are presented in fig 8 respectively.

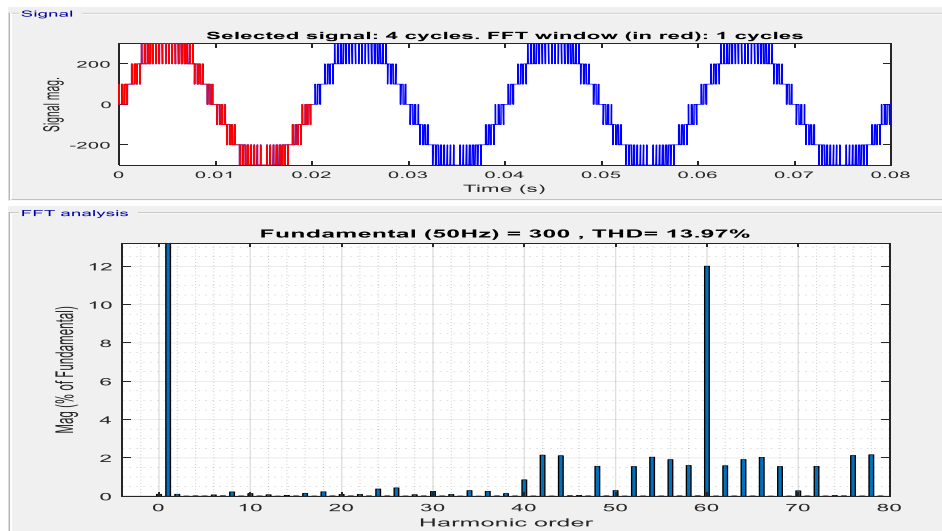


Fig. 3. THD of the input signal

In Fig 3, presented about Total Harmonic Distortion (THD) measured for input step signal. The THD analysis of the input step signal stated that Fast Fourier Transform (FFT) analysis of. The average percentage reduction of PM-SCHM scheme with existing technique line voltage THD reduction average of 74.3795% rather than existing technique.

In table 2 presented about parameters measured for the proposed PM-SCHM scheme and in table 3 shows comparative analysis of THD reduction is presented with existing technique.

Table. 2 PM-SCHM Measured Values

Parameters	Measured	THD Measured
Input Voltage (V) in 3 -phase	100	13.97
Line Voltage (V)	600	5.33
Phase Voltage (V)	250	5.31
Phase Current	2.25	16.49



Table. 3. Comparative analysis of THD with ref 12 and 13

Parameters	Optimization [13]	Vsi Based_ [12]	Topology Dstatcom	THD of PM-SCHM	Average % Reduction in THD of proposed PM-SCHM
Input Voltage (V) in 3 -phase	18.49	25.0		13.97	24.446
Line Voltage THD	16.45	28.29		5.33	67.599
Phase Voltage THD	10.78	6.67		5.31	50.74
Phase Current THD	26.78	-		16.49	38.4242

IV. CONCLUSION

THD degrades overall performance of electrical system with reduced efficiency. To overcome THD in multi-level inverter this research developed a PM-SCHM scheme. The proposed scheme integrates H-bridge inverter assembled with linear quadratic regulator (LQR) design. The designed multi-level inverter is assigned in cascaded design for reducing THD at 5th harmonics. The designed PM-SCHM scheme performance is measured in terms of THD phase voltage and phase current. Comparative analysis of simulation results stated that proposed PM-SCHM scheme exhibits significant reduction in THD. The average reduction in THD for input voltage, line voltage, phase current and phase voltage of 44.12%, 24.446%, 35.57% and 16.49% respectively. The arrangement of components in LQR with shunt filter design reduces the ripple current which in turns minimizes THD of the multilevel inverter. In the future, this research can be applied to the power grid for resolving optimization and harmonic distortion.

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