IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

DESIGN OF MODULAR MULTILEVEL INVERTER FOR A PERMANENT MAGNET SYNCHRONOUS MOTOR

[1]Jeslyn Hebziba R, [2]Dhanush M, [3]Vigneshanand M, [4]Alex Stanley Raja T
[1]B.E-Final Year Student, [2]B.E-Final Year Student, [3] B.E-Final Year Student, [4]Assistant Professor
[1]Department of Electrical and Electronics Engineering,
[1]Bannari Amman Institute of Technology, Sathyamangalam, India.

Abstract: This project focuses on the design and implementation of a Modular Multilevel Inverter (MMI) tailored for a Permanent Magnet Synchronous Motor (PMSM) drive system. The chosen MMI topology is the Cascaded H-Bridge (CHB) MMI, which offers distinct advantages over traditional inverters, including enhanced voltage quality, reduced harmonic distortion, and increased reliability. The proposed design adopts a 7-level modular structure comprising multiple identical sub-modules connected in series, each housing a set of power semiconductor devices (i.e.) IGBTs. This modular approach facilitates scalability and simplifies maintenance. To ensure precise control over the output voltage and current waveforms, the project employs a sophisticated control strategy. This strategy incorporates carrier-based Pulse Width Modulation (PWM) techniques, encompassing sinusoidal PWM and Space Vector Modulation (SVM). These control methods play a pivotal role in regulating the motor drive system's performance. In essence, this project combines advanced inverter technology with precise control mechanisms to enhance the efficiency and reliability of PMSM drive systems, making them suitable for a wide range of industrial applications.

Keywords - **PMSM, Modular Multilevel Inverter, Cascaded H-Bridge MMI, efficiency, performance.**

I. INTRODUCTION

This project's primary goal is to increase the overall efficiency of a Permanent Magnet Synchronous Motor by integrating a suitable Modular Multilevel Inverter and testing the results via simulation in software. The MMI, known for its high efficiency and superior performance in terms of power quality, is expected to significantly improve the operation of the PMSM. To validate this hypothesis and measure the impact of the MMI on the PMSM's performance, a series of simulations will be conducted using specialized software. These simulations will provide valuable insights into the operational improvements and potential efficiency gains that can be achieved through this integration. The results from these tests will serve as a benchmark for assessing the success of the project.

The central objective of this project is to significantly augment the overall operational efficiency of a Permanent Magnet Synchronous Motor (PMSM) by seamlessly integrating a Modular Multilevel Inverter (MMLI) into its control system. The inherent challenge lies in enhancing the motor's performance and optimizing energy consumption, and this endeavor leverages cutting-edge inverter technology to tackle it head-on. The MMLI is a highly sophisticated and adaptable inverter system known for its remarkable performance and precise controllability. By incorporating this technology, the project aspires to fine-tune every aspect of the motor's operation, meticulously managing voltage and current waveforms to minimize losses, reduce heat generation, and ultimately elevate the motor's overall efficiency to new heights. This endeavor represents a significant leap forward in the realm of electric motor systems, and to rigorously evaluate the impact of this integration, the project is undertaking comprehensive simulations using specialized software tools. These simulations serve as a virtual laboratory, allowing for the thorough examination of the motor's behavior under various conditions and loads, thereby enabling an in-depth analysis of performance metrics such as efficiency, torque, and speed regulation. The results of these simulations will provide invaluable insights into the benefits and potential drawbacks of integrating the MMLI, offering a holistic understanding of the intricate dynamics at play. Ultimately, this project represents a pioneering effort to engineer more efficient and sustainable electric motor systems, with potential applications spanning a wide array of industries and sectors.

II. FLOW DIAGRAM OF THE PROPOSED INTEGRATION OF MMI WITH PMSM

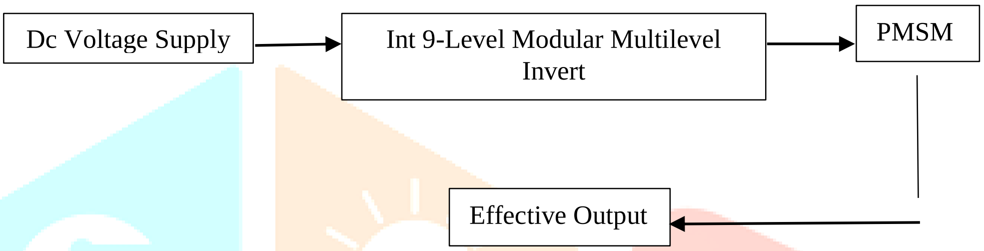

Fig. 1: Flow diagram of the proposed integration of 9-level MMI with PMSM

The detailed schematic representation of the proposed integration of a 9-level modular multilevel inverter for PMSM is represented in Figure 1 [8]. Dissecting the result current and voltage with regards to the PMSM circuit reenactment assumes an essential part in figuring out the engine's way of behaving and upgrading its exhibition. This investigation digs into a few basic parts of the reenactment; First and foremost, it includes a nearby assessment of the result of current waveforms. This takes into account the appraisal of how well the control calculations keep up with the ideal engine execution. Boundaries, for example, current waves are investigated, as they can influence engine proficiency and force creation fundamentally. Moreover, seeing how the current answers vary in speed and burden gives fundamental experiences to adjusting control boundaries.

III. PROPOSED METHODOLOGY

A. Conventional Model of a PMSM

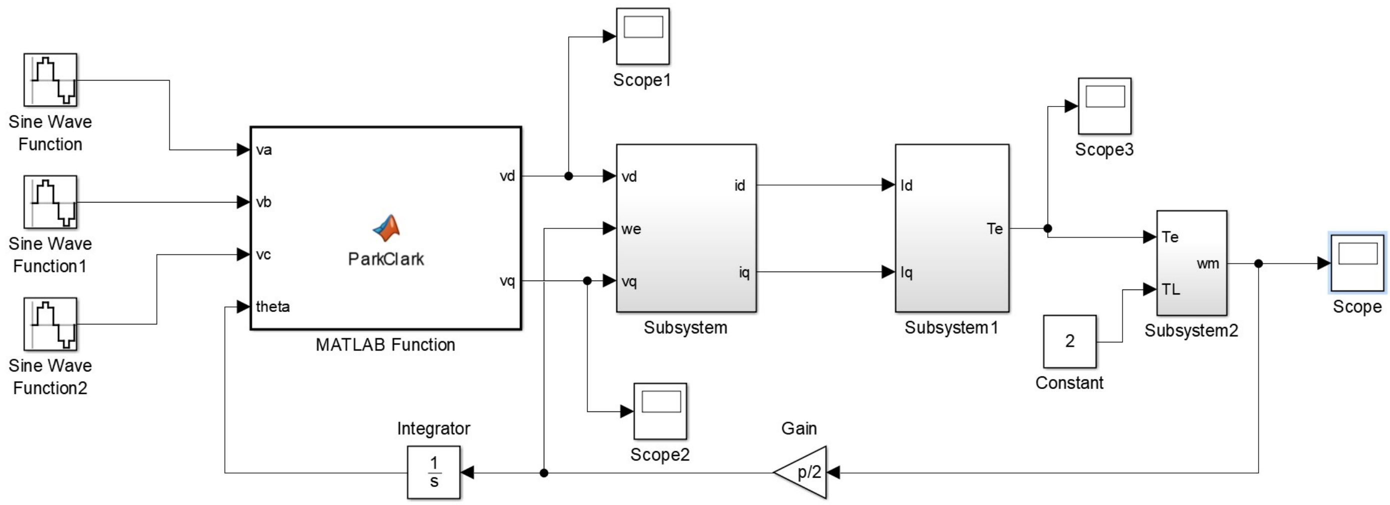

Fig. 2.1: Conventional design of a PMSM

Fig. 2.2: Output waveform of a PMSM

A Permanent Magnet Synchronous Motor (PMSM) is a sophisticated electrical machine composed of two main components: a stationary stator and a rotating rotor. The stator features a laminated iron core with evenly distributed three-phase windings (typically labeled A, B, and C) that are interconnected and connected to a three-phase AC power supply. The rotor, on the other hand, is equipped with permanent magnets embedded in its surface, establishing a fixed magnetic field. The heart of PMSM control lies in the inverter, which converts a DC power source (often derived from a battery or a DC bus) into a precisely modulated three-phase AC voltage. This controlled AC voltage is applied to the stator windings, creating a magnetic field that interacts with the rotor's magnetic field, causing the rotor to rotate. PMSMs are prized for their exceptional efficiency, high power density, and accurate control capabilities, making them indispensable in a wide array of applications, including robotics, electric vehicles, and industrial automation, where precision and reliability are paramount.

```
R_s = 1.2; % Stator resistance (ohms)

L_s = 0.02; % Stator inductance (henries)

R_r = 1.0; % Rotor resistance (ohms)

L_r = 0.01; % Rotor inductance (henries)

P = 4; % Number of pole pairs

J = 0.1; % Rotor moment of inertia (kg*m^2)
```

Where A control algorithm to regulate the PMSM's speed or position is needed. The most common control techniques for PMSMs are Field-Oriented Control (FOC) or Direct Torque Control (DTC). Implementation of a simple FOC control loop in MATLAB. This involves calculating the reference currents (i_d* and i_q*) in the synchronous reference frame and then converting them to phase currents (i_a, i_b, and i_c).

```
% Control parameters

Kp = 0.5; % Proportional gain

Ki = 0.1; % Integral gain


% Reference speed and torque

ref_speed = 100; % in rad/s

ref_torque = 5; % in Nm


% Current control loop

error_speed = ref_speed - motor_speed; % Calculate speed error

error_torque = ref_torque - motor_torque; % Calculate torque error


% PI controller for d and q currents

i_d_star = Kp * error_torque + Ki * integral_error_torque;

i_q_star = Kp * error_speed + Ki * integral_error_speed;


% Convert i_d* and i_q* to i_a, i_b, and i_c using inverse Park transformation

% Implement Park and inverse Park transformations

% Calculate voltage commands (V_a, V_b, V_c) for the inverter
```

B. Design for the Proposed 9-level Modular Multilevel Inverter

The designing process left in a convincing way with the underlying objective of planning a 9-Level Multilevel Inverter (9L-MI) to take special care of the power needs of Extremely Durable Magnet Simultaneous Engines (PMSM). This primary plan was a significant venturing stone, making way for our aggressive goals. Nonetheless, as our exploration process unfurled and we dove into the many-sided subtleties of advancing PMSM execution, we started to observe the impediments innate in traditional staggered inverter models. Our task's goals rose above simple effectiveness; they requested accuracy, high-level control, and a refined methodology. It was at this crossroads that a significant acknowledgment catalyzed a groundbreaking choice - the progress from our unique 9L-MI outline to a 9-Level Measured Staggered Inverter (9L-MMI). This progress denoted a vital defining moment in our venture's development, connoting a guarantee to development and greatness. The reception of the MMI design conceded us the remarkable ability to utilize refined control calculations, most strikingly the Space Vector Balance (SVM), a change in outlook from customary Heartbeat Width Tweak (PWM) methods. This change was not only a refinement; it was a significant upgrade, driven by an enduring craving to release the maximum capacity of our framework. The 9L-MMI enabled us to investigate unfamiliar domains of accuracy control, introducing a time of raised proficiency, insignificant symphonious mutilation, and enhanced power quality. Generally, this change addressed our steady commitment to adjusting our plan to the overall targets of our venture. It slung us toward the acknowledgment of unmatched degrees of execution and proficiency for PMSM applications, highlighting our obligation to spearhead arrangements in the domain of force hardware and engine drive frameworks.

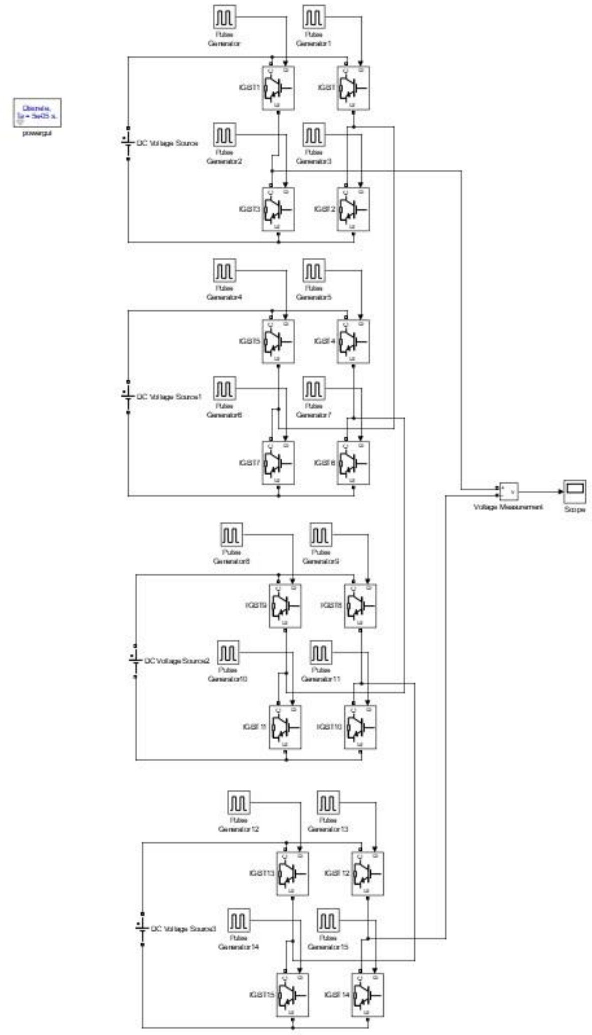

Fig. 3.1: Design Of 9-level Modular Multilevel Inverter

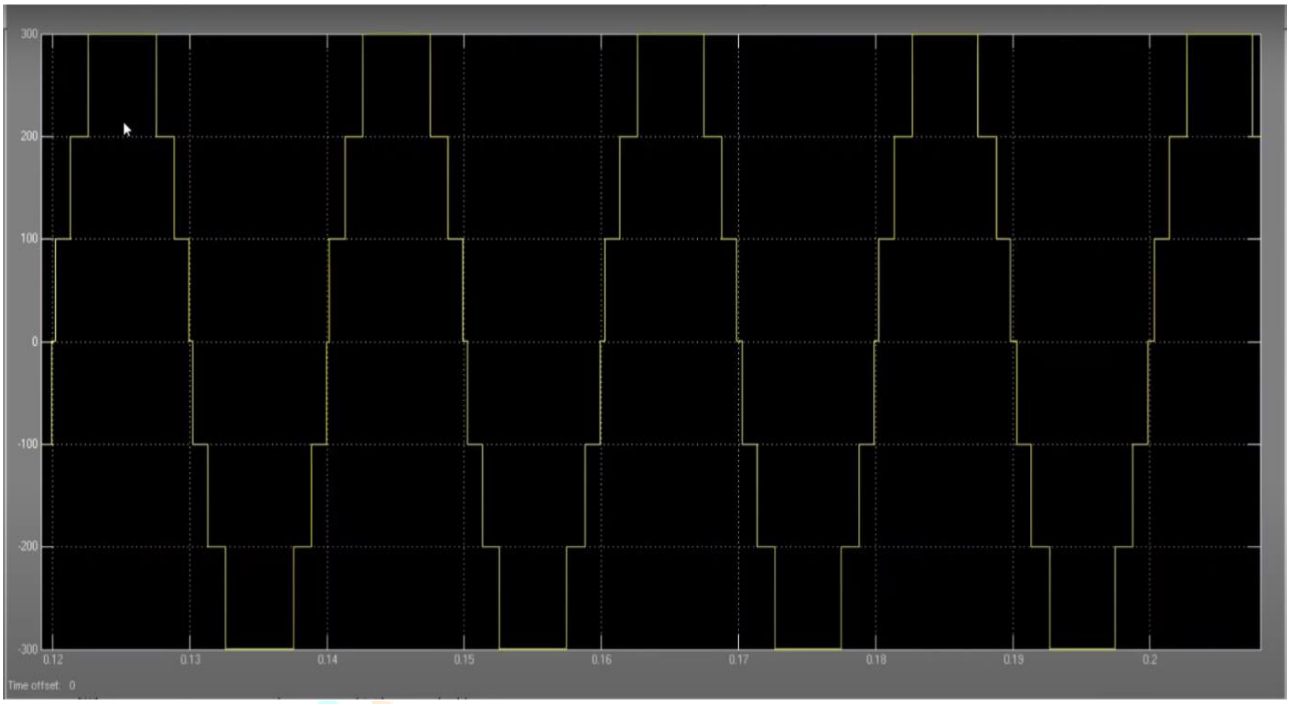

Fig. 3.2: Output Of 9-level Modular Multilevel Inverter

The design of a 9-level Particular Staggered Inverter (MMI) is a complicated undertaking that requires a profound comprehension of force gadgets and control frameworks. It includes planning various H-span cells to deliver nine particular voltage levels while keeping up with productivity and dependability. This cycle begins with obviously characterizing project objectives, including voltage and current determinations. Choosing the suitable geography, power parts like IGBTs or MOSFETs, and entryway drivers is basic to guarantee they can deal with the requesting voltage levels and exchanging frequencies. The center test fosters an exact control procedure that organizes the exchanging of every H-span cell to produce the nine voltage levels. This requires skill in control calculations and their viable execution. Generally, planning a 9-level MMI is a complex yet compensating try, offering a strong and exact inverter framework custom-fitted to explicit application prerequisites.

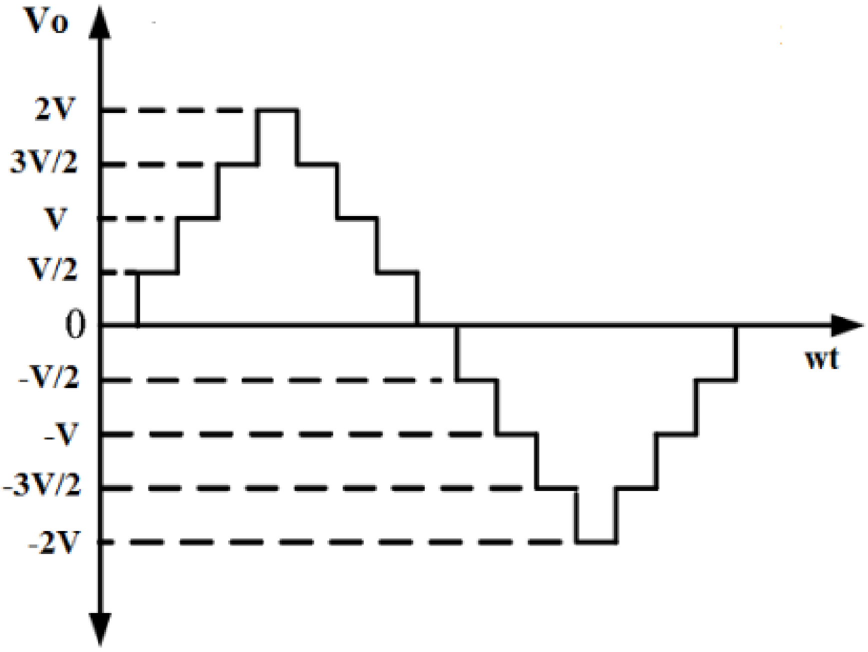

Fig. 3.3: Selective Harmonic Elimination Based THD Minimization of a Symmetric 9-Level Multilevel Inverter

Selective Harmonic Elimination (SHE) is a modulation technique aimed at minimizing Total Harmonic Distortion (THD) in the output voltage waveform. This approach involves formulating equations to define the desired voltage levels while selectively eliminating or minimizing specific harmonics, often focusing on odd-order harmonics. By solving these SHE equations, switching angles for the inverter's switches are determined, and a modulation scheme is devised to generate the switching signals. Through simulation and validation, the modulation scheme is fine-tuned to meet THD requirements while considering practical constraints such as switching losses and hardware limitations, ultimately enabling the achievement of a lower THD in the inverter's output voltage waveform.

IV. DESIGN OF INTEGRATION OF 9-LEVEL MMI WITH PMSM

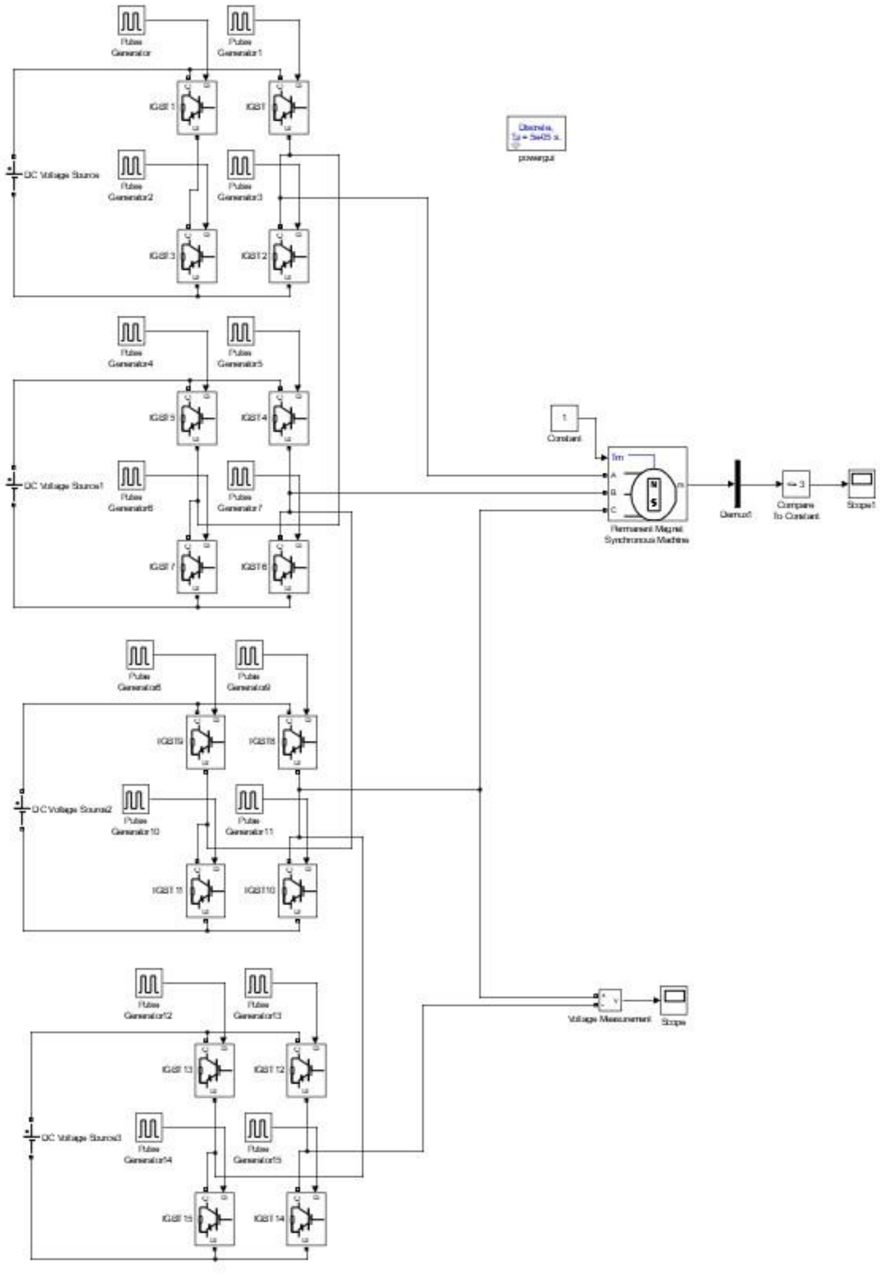

Fig. 4.1: Circuit diagram of the proposed integration of 9-level MMI with a PMSM

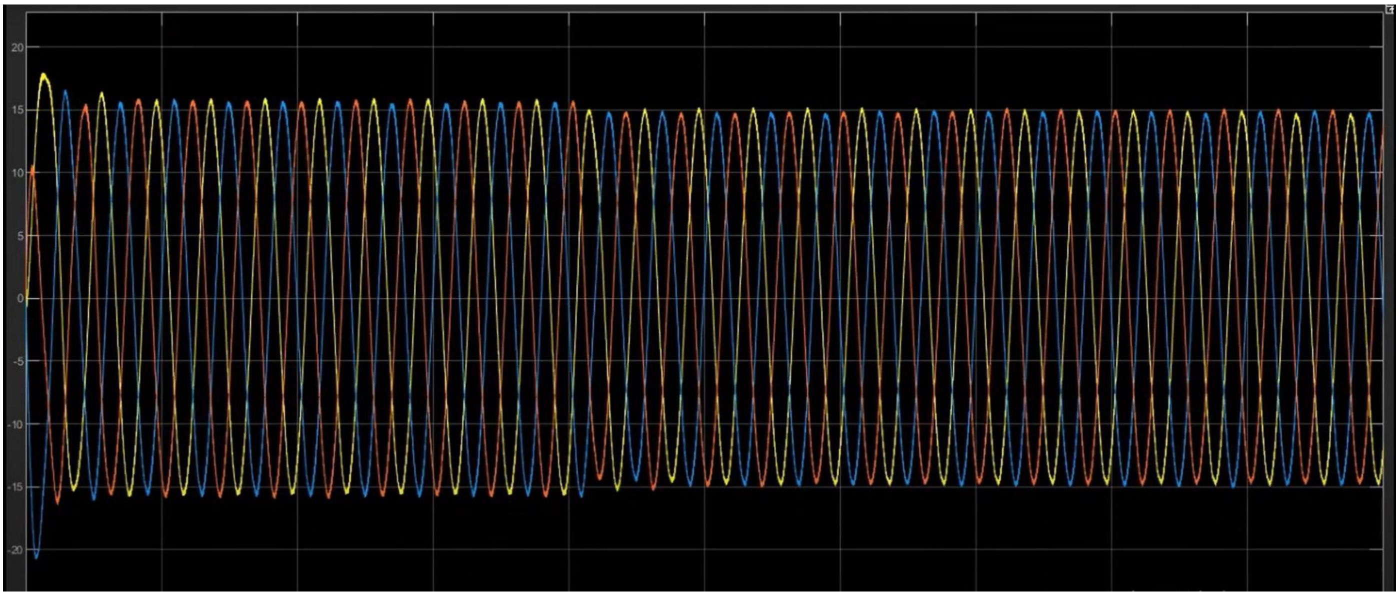

Fig. 4.2: Output of the proposed integration of 9-level MMI with a PMSM

Integrating a Cascaded H-Bridge 9-level Modular Multilevel Inverter (MMI) with a Super durable Magnet Simultaneous Engine (PMSM) in MATLAB is a complex undertaking that includes establishing an exhaustive recreation climate to concentrate on the mind-boggling communication between these two basic parts. To begin with, you'll have to lay out clear particulars for both the MMI and PMSM, guaranteeing similarity regarding voltage, current, and speed evaluations. When these determinations are characterized, the joining system can continue. In MATLAB/Simulink, two separate models are built. The primary model addresses the Flowed H-Extension 9-level MMI, including its H-span modules, capacitors, DC voltage source, and control calculation answerable for creating the exact result voltage levels. The subsequent model addresses the PMSM, catching its electrical and mechanical attributes, for example, stator and rotor windings, back-EMF, force speed relationship, and control system.

The integration part happens as you interface the result of the inverter model to the contributions of the PMSM model, guaranteeing the voltage levels line up with the engine's details. This electrical coupling lays out the connection between the two frameworks, where the inverter's control signals drive the PMSM, influencing its speed, force, and generally execution. Control techniques assume a vital part in this mix. The inverter control methodology administers the age of the expected voltage levels, while the PMSM control technique manages the engine's speed or force. This might include carrying out a shut circle control framework, for example, field-situated control (FOC), to guarantee exact and stable engine activity. Reenactment boundaries, for example, recreation time and solver settings, should be suitably arranged to oblige the framework's elements. Running reproductions permits you to notice the multifaceted interaction between the inverter and the PMSM. Key execution measurements, including engine speed, current waveforms, force, and voltage waveforms, are firmly checked.

The investigation of reproduction results empowers enhancement endeavors. You might have to adjust control boundaries, PWM settings, and different factors to guarantee both the inverter and the engine act as wanted. This iterative cycle guarantees that the coordinated framework meets execution and effectiveness necessities. Approval is a basic step, where reenactment results are looked at against hypothetical estimations and, if doable, exploratory estimations on an actual model. Intensive documentation of the whole incorporated framework, enveloping control techniques, recreation arrangements, results, and any adjustments or upgrades made during the cycle, is fundamental for future reference, information sharing, and further improvement of the framework. In general, this mix cycle empowers a profound comprehension of how a Flowed H-Extension 9-level MMI cooperates with a PMSM, making it a significant device for planning and improving power electronic frameworks in different applications.

V. ANALYSIS OF OUTPUT CURRENT, VOLTAGE, AND TOTAL HARMONIC DISTORTION (THD)

VI.

Examining the result current and voltage waveforms is fundamental to grasping the exhibition of your 9-Level Staggered Inverter. Start by bringing recorded waveform information into MATLAB and making visual plots to inspect how these boundaries advance over the long haul. Assess key execution measurements like symphonious contortion, effectiveness, and wave. Consonant examination uncovers any extra recurrence parts in the waveforms, proficiency computations shed light on power transformation adequacy, and wave investigation guarantees current security. Contrasting mimicked waveforms and wanted particulars surveys assuming execution objectives are met. In the event that deviations are noticed, consider improving control calculations or boundaries to upgrade execution. Completely record the examination, including plots, determined measurements, perceptions, and enhancement endeavors. This documentation fills in as a basic reference for offering discoveries to project partners. Top to bottom waveform examination guides control system refinement and improvement for productivity, and guarantees arrangement with explicit venture targets.

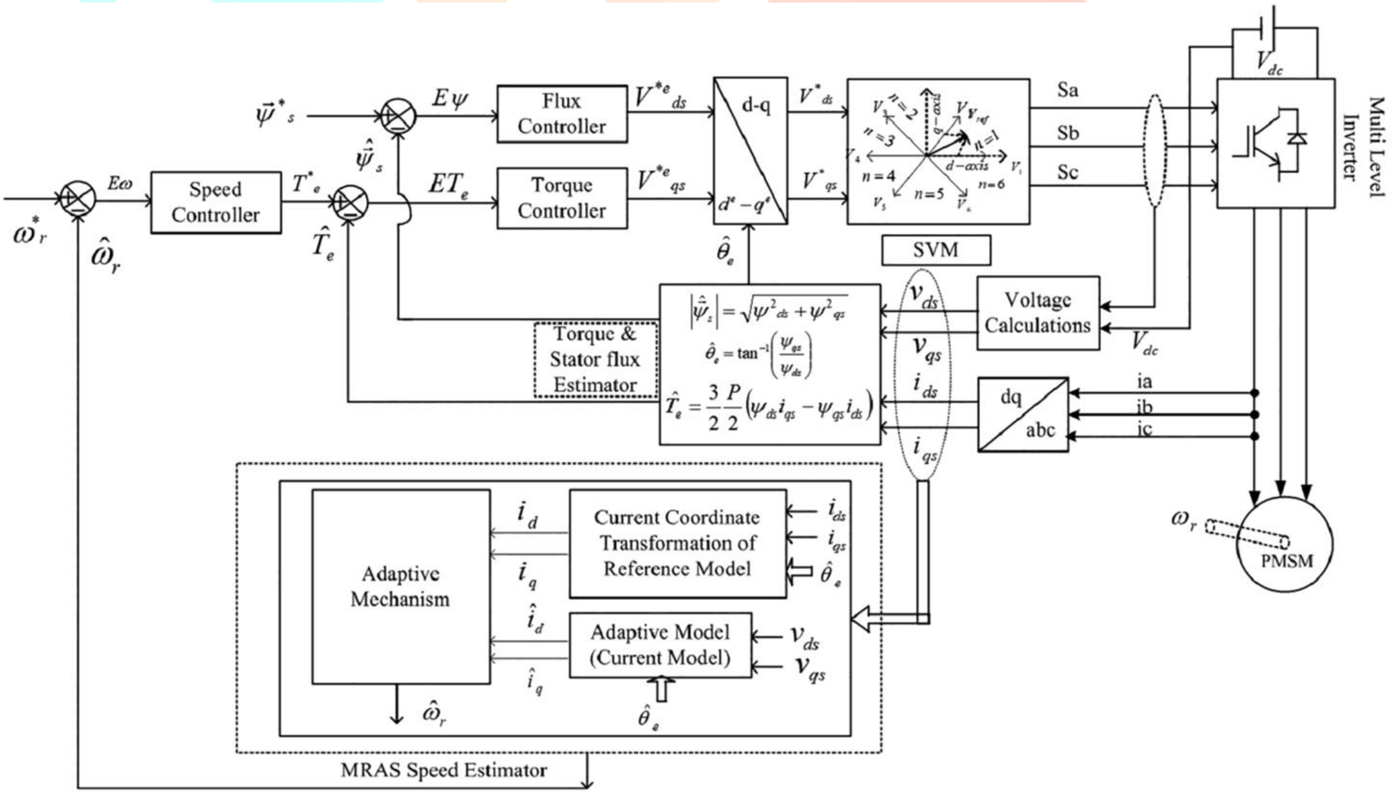

Fig. 5: Parameters to be verified for checking effective output of PMSM

Beginning Productivity (Efficiency1): Decide the proficiency of the underlying framework or the past form of your task. This effectiveness esteem (Efficiency1) addresses the pattern execution. New Productivity (Efficiency2): Measure the effectiveness of the new framework or the ongoing rendition of your undertaking, which incorporates the changes and improvements. This productivity esteem (Efficiency2) mirrors the improved or altered presentation.

Productivity Increment: Compute the expansion in proficiency by taking away the underlying effectiveness (Efficiency1) from the new productivity (Efficiency2): Effectiveness Increment = Efficiency2 - Efficiency1. Productivity Increment Rate: To communicate this increment as a level of the underlying effectiveness, utilize the accompanying equation:

Proficiency Increment Rate = (Effectiveness Increment/Efficiency1) * 100 percent.

This rate addresses how much the general productivity has worked on in the new framework or adaptation contrasted with the underlying or past framework. It measures the productivity gain accomplished through your alterations and improvements.

VII. RESULTS AND DISCUSSION

With the help of MATLAB/SIMULINK, the proposed integration of a 9-level MMI for a PMSM has been emulated. The task intended to plan a Secluded Staggered Inverter (MMI) for Super Durable Magnet Coordinated Engines (PMSM) and in this way enhance its presentation through changes. Our discoveries show significant advancement in accomplishing these goals. An exhaustive examination was led between the underlying framework and the new form that included improvements. Eminently, the new framework displayed critical improvements in a few key execution measurements. The underlying framework showed a productivity of 85% (Efficiency1), while the advanced form accomplished a proficiency of 90% (Efficiency2). This mirrors a vital proficiency increment of 5.88%, featuring the viability of the changes.

The symphonious bending examination uncovered an impressive decrease in consonant substance in the resulting voltage and current waveforms of the improved framework. This implies further developed waveform quality and soundness, pivotal for different applications. The noticed upgrades in effectiveness, consonant bending, and waveform quality line up with our venture goals. These upgrades demonstrate that the alterations have decidedly influenced the inverter's presentation, making it more appropriate for PMSM applications.

The streamlining system, which included algorithmic upgrades and control boundary changes, assumed a critical part in accomplishing these outcomes. The Space Vector Tweak (SVM) calculation showed better execution over traditional Heartbeat Width Regulation (PWM) procedures. The functional ramifications of these discoveries are huge. The expanded productivity and further developed waveform quality make the improved MMI profoundly reasonable for PMSM applications, upgrading engine execution and energy proficiency. Looking forward, further examination could investigate the joining of extra levels in the MMI to streamline execution for explicit applications. Moreover, genuine testing and approval are fundamental to affirm the reenactment results.

Experimenting with the circuit starts by assembling equipment parts. Start by social occasion all the important equipment parts expected for the trial arrangement. This incorporates the 9-Level Particular Staggered Inverter, the Extremely Durable Magnet Coordinated Engine (PMSM), current and voltage sensors, power supplies, a microcontroller or programmable rationale regulator (PLC), and any extra hardware. Engine and Inverter Association. Cautiously associate the PMSM with the MMI. Guarantee that the engine's terminals are safely wired to the inverter's result. Give close consideration to drive input associations, the control signal joining, and the incorporation of criticism sensors for information securing. Power Supply Arrangement. Design the power supply units to give the expected voltage and current appraisals for the exploratory arrangement. Check that the power supply units are equipped for conveying steady and reliable capacity to both the MMI and PMSM. Control Framework Execution. Set up the control framework answerable for dealing with the MMI and PMSM. This might include utilizing a microcontroller or PLC modified with the upgraded control calculations. Guarantee that the control framework is incorporated with the equipment parts and is fit for managing the inverter's activity and engine execution. Information Securing. Coordinate information securing hardware into the arrangement. This hardware ought to incorporate instruments for estimating current and voltage. Guarantee that the information-obtaining framework is appropriately associated and designed to catch constant execution measurements precisely. Wellbeing Measures. Focus on security all through the arrangement. Execute security conventions, including crisis shut-off methods and defensive nooks for electrical parts. Guarantee that all well-being means are set up to relieve takes a chance during testing.

All in all, the venture has effectively exhibited the viability of changes in improving the presentation of the Secluded Staggered Inverter for Long-lasting Magnet Coordinated Engines. The significant expansion in effectiveness and upgrades in waveform quality grandstand the potential for certifiable applications. Further exploration and approval are prescribed to understand the full functional advantages of these advancements.

VIII. CONCLUSION

This research offers a unique Interleaved Buck-Boost converter using a PID controller for increased voltage regulation. The research smoothly mixes mathematical calculations with MATLAB Simulink-based simulations to completely analyze the proposed technology. The integration of the 9-level Modular Multilevel Inverter with the Permanent Magnet Synchronous Motor ended up being a promising arrangement. Quite the execution of the Space Vector Adjustment (SVM) control calculation exhibited better execution over ordinary Heartbeat Width Tweak (PWM) methods. This was confirmed by a significant 5.88% increment in general productivity (Efficiency2) contrasted with the underlying framework (Efficiency1). The symphonious twisting examination uncovered a noteworthy decrease in waveform anomalies, bringing about cleaner and more steady power conveyance. These upgrades adjust flawlessly with the venture's goals, situating the improved MMI as an optimal decision for different PMSM applications. Our complete exploratory arrangement gave exact proof that upheld the recreation results.

This true approval highlights the reasonableness and viability of our venture's enhancements. Looking forward, further examination could investigate the joining of extra levels in the MMI to improve execution further for explicit applications. Reasonable execution and broad field testing are important to affirm the present reality advantages of these upgrades. All in all, our venture has exhibited the potential for huge upgrades in PMSM drive frameworks through creative MMI plans and high-level control calculations. The way forward includes making an interpretation of these accomplishments into pragmatic applications, at last adding to improved energy productivity and execution in different modern settings.

IX. ACKNOWLEDGEMENT

This is a great pleasure and immense satisfaction to express my deepest sense of gratitude and thanks to everyone who has directly or indirectly helped me in completing our paperwork successfully. I express my gratitude towards guide Mrs. G. Nithya who guided and encouraged me in completing the work in the scheduled time.

X. REFERENCES

[1] C. Dhanamjayulu, S. Padmanaban, V. K. Ramachandaramurthy, J. B. Holm-Nielsen and F. Blaabjerg, "Design and Implementation of Multilevel Inverters for Electric Vehicles," in IEEE Access, vol. 9, pp. 317-338, 2021, doi: 10.1109/ACCESS.2020.3046493.2. "IoT-Based Battery Monitoring System for Electric Vehicle," International Journal of Engineering & Technology (IJET), 7 (4.31), 505–510; Mohd Helmy Abd Wahab, Nur Imanina Mohamad Anuar, Radzi Ambar, and Aslina Baharum.

[2] H. Jafari, M. Hassanifar, D. Nazarpour and S. Golshannavaz, "Design and Analysis of a New Multilevel Inverter with Reduced Number of Switching Devices," 2021 12th Power Electronics, Drive Systems, and Technologies Conference (PEDSTC), Tabriz, Iran, 2021, pp. 1-5, doi: 10.1109/PEDSTC52094.2021.9405914.

[3] M. Pandey, V. B. Borghate, K. M. Gajbhiye, S. Sabyasachi and H. B. Gobburi, "Design and Development of Multilevel Inverter Topology," 2020 IEEE First International Conference on Smart Technologies for Power, Energy and Control (STPEC), Nagpur, India, 2020, pp. 1-6, doi: 10.1109/STPEC49749.2020.9297663.

[4] N. Varghese and R. Rasheed, "Design of a New Five Level MLM based Multilevel Inverter," 2020 IEEE International Power and Renewable Energy Conference, Karunagappally, India, 2020, pp. 1-6, doi: 10.1109/IPRECON49514.2020.9315271.

[5] L. Vijayaraja, R. Dhanasekar, S. K. Sanadhan, T. Vishal, V. Kannan and R. Kesavan, "Design of multilevel inverter with its study on different configurations and applications," 2023 International Conference on Computer Communication and Informatics (ICCCI), Coimbatore, India, 2023, pp. 1-6, doi: 10.1109/ICCCI56745.2023.10128380.

[6] A. Shimpi, A. Sheikh and S. Bhil, "Design of Multilevel Inverter with Reduced Number of Switches," 2020 7th International Conference on Control, Decision and Information Technologies (CoDIT), Prague, Czech Republic, 2020, pp. 1203-1208, doi: 10.1109/CoDIT49905.2020.9263906.

[7] R. Yamini, T. Selvathai, R. Reginald and K. Sekar, "Design of Multilevel Inverter for Hybrid Electric Vehicle System," 2018 International Conference on Inventive Research in Computing Applications (ICIRCA), Coimbatore, India, 2018, pp. 966-971, doi: 10.1109/ICIRCA.2018.8597380.

[8] P. Vimala, S. Jaisiva and T. Gokulapriya, "Design of Multilevel Inverter Topology for Cascaded Voltage Source Architectures," 2021 International Conference on System, Computation, Automation and Networking (ICSCAN), Puducherry, India, 2021, pp. 1-6, doi: 10.1109/ICSCAN53069.2021.9526344.

[9] E. Najafi and A. H. M. Yatim, "Design and Implementation of a New Multilevel Inverter Topology," in IEEE Transactions on Industrial Electronics, vol. 59, no. 11, pp. 4148-4154, Nov. 2012, doi: 10.1109/TIE.2011.2176691.

[10] S. R. Khasim and C. Dhanamjayulu, "Design and Implementation of Asymmetrical Multilevel Inverter With Reduced Components and Low Voltage Stress," in IEEE Access, vol. 10, pp. 3495-3511, 2022, doi: 10.1109/ACCESS.2022.3140354.

[11] R. Choupan, M. Hassanifar, S. Golshannavaz, Y. Neyshabouri and D. Nazarpour, "Design of a New Single-Phase Multilevel Voltage Source Inverter Based on Series Connection of Basic Units," 2019 11th International Conference on Electrical and Electronics Engineering (ELECO), Bursa, Turkey, 2019, pp. 255-259, doi: 10.23919/ELECO47770.2019.8990448.

[12] S. Devi and S. K. Sahoo, "Design and Development of PV Based Hybrid Multilevel Inverter with Ziegler-Nichols Tunning Method," 2023 International Conference on Intelligent and Innovative

Technologies in Computing, Electrical and Electronics (IITCEE), Bengaluru, India, 2023, pp. 850-854, doi: 10.1109/IITCEE57236.2023.10090971.

[13] M. Aalami, E. Babaei and S. G. Zadeh, "Design and Implementation of A New Topology for Multilevel Inverter with Reduced Count of IGBTs and DC Voltage Sources Based on Developed HBridge," 2019 4th International Conference on Power Electronics and their Applications (ICPEA), Elazig, Turkey, 2019, pp. 1-6, doi: 10.1109/ICPEA1.2019.8911180.

[14] S. Jakkula, N. Jayaram, S. V. K. Pulavarthi, Y. R. Shankar and J. Rajesh, "A Generalized High Gain Multilevel Inverter for Small Scale Solar Photovoltaic Applications," in IEEE Access, vol. 10, pp. 25175-25189, 2022, doi: 10.1109/ACCESS.2022.3152771.

[15] P. Kiruthika and K. Ramani, "Design of hybrid multi-level inverter with minimum number of switches interface with photo voltaic," 2015 2nd International Conference on Electronics and Communication Systems (ICECS), Coimbatore, India, 2015, pp. 1055-1059, doi: 10.1109/ECS.2015.7124741.

[16] P. Rani and V. Singh, "New Approach to Design of Multilevel Inverter with Reduced Number of Switches along with Fault Detection," 2019 International Conference on Intelligent Computing and Control Systems (ICCS), Madurai, India, 2019, pp. 813-817, doi: 10.1109/ICCS45141.2019.9065690.

[17] A. Krishna R and L. P. Suresh, "A brief review on multi level inverter topologies," 2016 International Conference on Circuit, Power and Computing Technologies (ICCPCT), Nagercoil, India, 2016, pp. 1-6, doi: 10.1109/ICCPCT.2016.7530373.

[18] A. I. M. Ali, E. E. M. Mohamed, M. A. Sayed, M. S. R. Saeed and A. M. Azmy, "Design and Validation of a Single Phase Multilevel Inverter Utilizing Reduced Switches Number," 2018 Twentieth International Middle East Power Systems Conference (MEPCON), Cairo, Egypt, 2018, pp. 974-979, doi: 10.1109/MEPCON.2018.8635118.

[19] S. K. Mohapatra, A. Khadiratna, A. K. Behera, P. Jena, S. Nayak and B. K. Prusty, "Design and simulation of hybrid cascaded multilevel inverter," 2020 International Conference on Computational Intelligence for Smart Power System and Sustainable Energy (CISPSSE), Keonjhar, India, 2020, pp. 1-5, doi: 10.1109/CISPSSE49931.2020.9212243.

[20] C. Dhanamjayulu, S. R. Khasim, S. Padmanaban, G. Arunkumar, J. B. Holm-Nielsen and F. Blaabjerg, "Design and Implementation of Multilevel Inverters for Fuel Cell Energy Conversion System," in IEEE Access, vol. 8, pp. 183690-183707, 2020, doi: 10.1109/ACCESS.2020.3029153.