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Solar powered space vector pulse width modulation based induction motor drive for industry applications

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ABSTRACT

The new millennium has witnessed a rapid growth in the development of solar-powered electric systems as well as variable frequency drives (VFDs). Predominantly, pulse width modulation (PWM) based adjustable frequency drives are being employed in the industry for providing superior performance. The space vector pulse width modulation (SVPWM) has gained importance due to its improved harmonic profile. In the current effort, SVPWM based VFD for an induction motor is devised equipped with a push-pull converter for optimal performance. A feedback system is incorporated for motor controls. The SVPWM is implemented using FPGA based my-RIO controller because of its effective processing and power handling capabilities; whereas the feedback control is furnished using Lab-View. The performance of the proposed scheme is analyzed. The results confirm flexible control of the motor incorporated with the presented drive system which is supplied via solar power.

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1. INTRODUCTION

Research efforts for decades have developed a lot of frequency and voltage control strategies for induction motors. Most often, voltage source inverter supplies variable frequency and voltage to three-phase induction motor for variable speed applications. Intensive work has been carried out on PWM for the last few decades. The chief purpose of modulation techniques is producing variable output preserving fundamental component maximum keeping harmonics minimum. PWM techniques broadly fall into SVPWM [1]-[5] and TCPWM [6]. PWM techniques largely are utilized for achieving variable speed and variable frequency in dc-ac and ac-dc converters [7], [8]. PWM applications also stand significantly in rectifiers for AC variable speed drives, uninterruptible power supplies, static frequency changers, [9]-[11]. Advanced drive systems for AC motors incorporate space vector control where the major issue of the harmonic distortion gets exterminated to a huge extent. Also, by PWM techniques, an increase in accuracy and reliability contributes to the complexity of the system.

Various controls were vigorously reviewed for the control of induction motors in [12]. In addition, both sensor and sensor-less controlling schemes with perspective of their operations, limitations and advantages were highlighted along their respective optimization techniques to overcome limitations. An algorithm of particle swarm optimization (PSO) was proposed in [13] for synchronization of damping torque coefficients and torque coefficients with less computation time. The modified form of multi carrier PWM was proposed in [14] for three-phase cascaded multilevel inverter (CMLI) with the usage of real time controller and simulator which escalates the accuracy with reduced harmonic components. Renewable power injection into the grid via filter was implemented through 3-phase multilevel cascaded H-bridge inverter [15], [16]. This work mainly performed two major contributions. Firstly, the total harmonic distortion was reduced by employing a passive filter; secondly, output voltages were increased due to 3-phase five-level inverter. Numerous control strategies of power electronics converter, permanent magnet synchronous generator (PMSG) and doubly fed induction generator (DFIG) were widely discussed in [17]. Performance analysis of clamping SVPWM based on down sampling for diode as well as cascaded Multi-level Inverter fed to induction motor drive was carried out in [18]. Another system employed DC-DC boost converter in continuous mode and three-level phase voltage source inverter in three-phase PV standalone system [19]. Moreover, another type of inverters with solar PV integeration are implemented in [20]-[22]. New methodology for maximum power point tracking and division of output voltage equal to the same voltage level by developing a quazi Z-source converter for power transfer was highlighted in [23].

Space vector modulation (SVM) technique has been incorporated in this work for projecting AC variable speed drive. In contrast to sinusoidal PWM, where 78.5% of fundamental is available in the linear region, SVM has 90.7% of fundamental in the linear region. SVM caters to primary THD issues along with secondary problems like switching losses [24]. SVM techniques have been implemented in various controllers including 8-bit low-cost micro-controllers [25] to neural networks [26]. In [27], [28] SVPWM based induction motor drive, energized by photovoltaic solar, was implemented using MATLAB/Simulink. Ismail *et al*. [29] SVPWM has been implemented on ATmega64 microcontroller for three-phase 2 level VSI. Some modifications were carried out on a generalized algorithm and then simulated in MATLAB and it was found out that these modifications improve the results. However, high-rated switches can't be triggered via Arduino signals, which is the case in current work. Existing work has also been found out incorporating DSP and dsPICs [30] to implement SVPWM with limitations in processing capacity and switching losses. Asma *et al*. [31] are presenting a comparative analysis of different processors for implementing SVPWM including DSP, dsPICs and ATmega328P where ATmega328 proved better owing to its advanced features. Even harmonics were exterminated with reduction of odd harmonic content with ATmega328P and generated SVPWM forms were symmetric. However, all aforementioned controllers' signals turn inapplicable to trigger high-rated switches for heavy inverter ratings.

In this paper, space vector pulse width modulation (SVPWM) based variable frequency drive has been implemented to operate a three-phase induction motor. Usually, the inverter is feed by a DC converter which reduces the current value. So, here push-pull converter has been incorporated to escalate the voltage level and meet the current requirement. The SVPWM technique is used for the inverter to convert the DC voltage into three-phase AC voltage and to design a feedback system to control the motor speed. The FPGA-based my RIO controller has been used to implement the SVPWM technique and feedback control system which is implemented in LABVIEW. As inverter switches require high voltage gate pulses that cannot be fulfilled with Arduino and other conventionally employed controllers that is why the my-RIO controller is a preferred choice.

2. EXPERIMENTAL MODELING

Hardware descriptions of every portion of the system including working parameters of all hardware parts have been elucidated. Block diagram and flow chart are given in Figure 1 and Figure 2 respectively. Here pushpull converter is used to step up the DC voltage of batteries, the three-phase inverter and its control system is providing constant AC voltage level to induction motor.

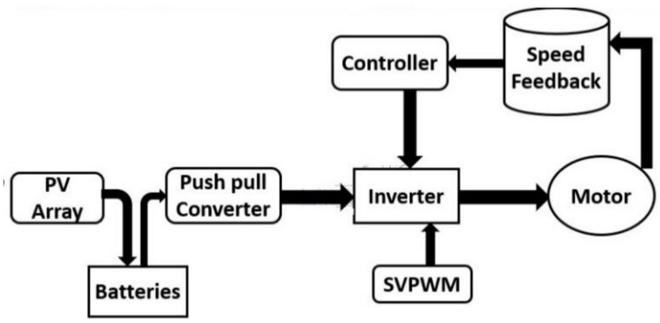


Figure 1. Block diagram of system

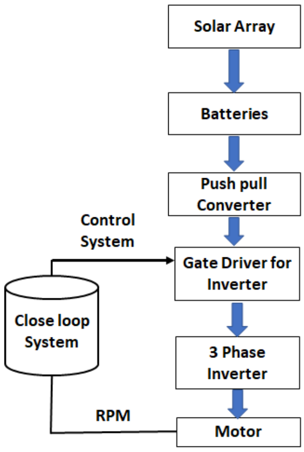


Figure 2. Flow chart of system

2.1. Solar panel

The specifications of solar panels have been given in the following Table 1. In this paper, the array of 4 panels is used to get the power of 1.1 KW. The solar array is charging the batteries, which are taken as input to push-pull inverter. A stable input voltage is required by push pull converter which is providing by batteries.

Table 1. Solar panel specifications

Parameters	Values
Rated power	275 Watt
Open circuit voltage	32 V
Short circuit current	9.42 A
Rated voltage	25 V
Rated current	7.28 A

2.2. Push-pull converter

"A DC to DC switched-mode power supply containing at least two semiconductor switches at least some energy storing elements, a capacitor, some IC's or the other elements in combination. Capacitors made filters are normally added to the output of the converter to reduce output voltage ripple". For escalation of voltage level, the push-pull converter has been used for variable AC-drive. The boost converter could also be employed but as it reduces the value of current for a specific increase in voltage level that is not enough for heavy induction motors. The switches are opened and closed alternatively with the rate of PWM switching frequency. Also, the transformer in the push-pull converter provides isolation of the system. Block diagram of the Push-pull converter is given in Figure 3. Push-pull converter specifications are given in Table 2.

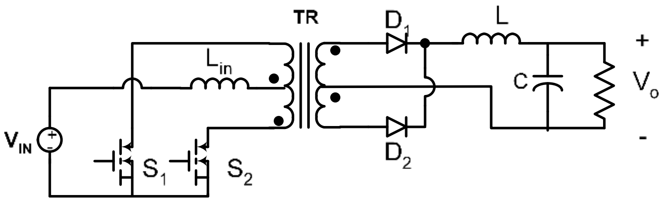


Figure 3. Push-pull converter block diagram

Table 2. Specifications of components of push-pull converter

Components	Model/rating
IC 3525(Pulse width modulator)	31kHz
Capacitor	450µF
Bridge current rating	5A
Output voltage rating	600V
Input voltage rating	24-48 V DC

2.3. Space vector pulse width modulation

The SVPWM technique is used to control switches of the inverter by giving it pulses. It is mostly used for inverter applications owing to its high-performance characteristics [20]. The three-phase inverter is treated as three separate push-pull inverter drive stages while SVPWM treats the inverter as a single unit while considering the machine as a mechanic load where the normally neutral is isolated, this causes interaction in phases [21]. This type of interaction was not taken over in previous PWM methods. The SVPWM optimizes the interaction of phases and harmonics of neutral load. In SVPWM the three-axis system is converted into a two-axis system. Clarke-Park transformation is used to transform the three-dimension ac quantities into two-dimension quantities dq0. In dq0 transformation the coordinates are perpendicular to each other and controllable and the PI controller can be applied to each quantity separately. The Clarke Park transformation is given as follows in (1).

$$\begin{bmatrix} x_d \\ x_q \\ x_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} cos(\theta) & cos\left(\theta - \frac{2}{3}\right) & cos\left(\theta + \frac{2}{3}\right) \\ sin(\theta) & sin\left(\theta - \frac{2}{3}\right) & sin\left(\theta + \frac{2}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix} \quad (1)$$

The model in dq coordinates can be get using in (2) and (3).

$$x_d = \frac{2}{3}\left(x_a - \frac{1}{2}x_b - \frac{1}{2}x_c\right) \quad (2)$$

$$x_q = \frac{2}{3}\left((0)V_a + \frac{\sqrt{3}}{2}(V_b) - \frac{\sqrt{3}}{2}(V_c)\right) \quad (3)$$

In (2) and (3) represent the d and q coordinate values. After the d and q values obtained from a, b and c values by suitable transformation equations the angle α can be found as in (4). The dq0 reference coordinates in vector form is shown in Figure 4.

$$\alpha = \tan^{-1}\left(\frac{V_d}{V_q}\right) \quad (4)$$

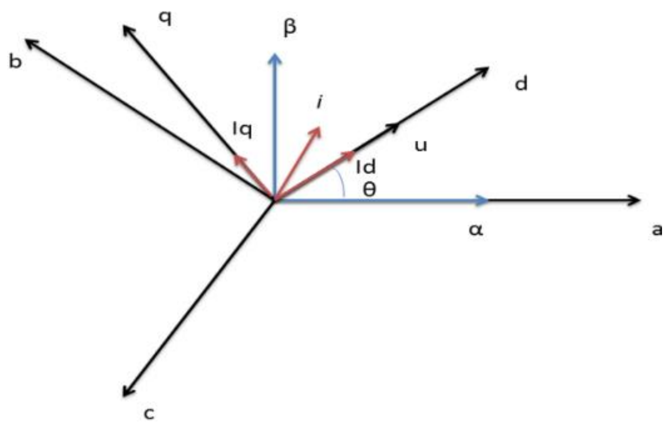


Figure 4. dq0 transformation of three-phase voltages

2.4. NI my RIO controller

To drive the inverter, PWM pulses are needed for the gate driver circuit. These pulses have a switching frequency in the range of (4kHz-10kHz). A high speed of code processing to produce these pulses at high frequency is mandatory, which has been fulfilled by a high computational speed controller known as NI my RIO. The algorithm of SVPWM is slow in other controllers because of the complex operation required in coding. This microcontroller (NI my RIO) can simplify this algorithm and runs the code at a higher speed. NI lab view has built-in packages for the programming required for the coding of NI my RIO controller. NI lab view 2016 is used for our project which makes it possible to interact with NI my RIO hardware. In LabView, we used graphical functional blocks to perform the operation required for SVPWM in a short time.

3. RESULTS AND DISCUSSION

This section elucidates the hardware design, results, waveforms, and conclusions. A hardware-based experimental setup is implemented and tested to get the desired results. A solar PV array of 1.1 KW is utilized to charge batteries. The batteries are set to provide 24 V at normal charging conditions. The overall integration of the PV array, battery storage with push-pull converter, inverter drive, AC motor, and SVPWM based controller is pictorially presented in Figure 5.

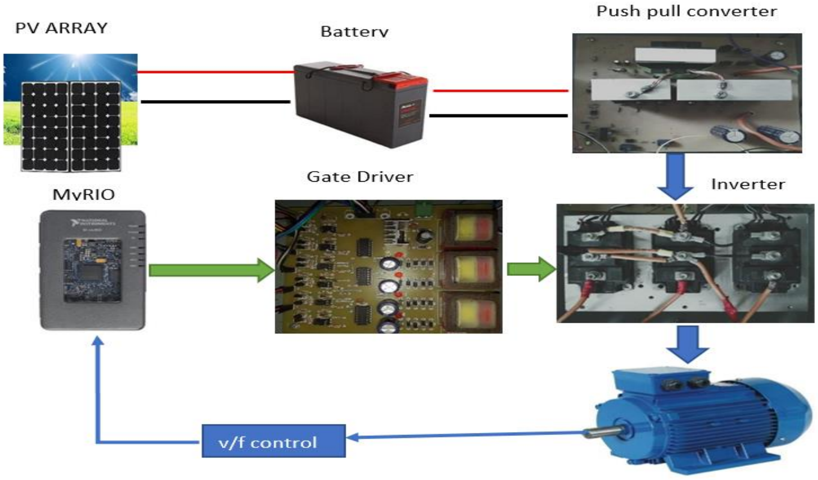
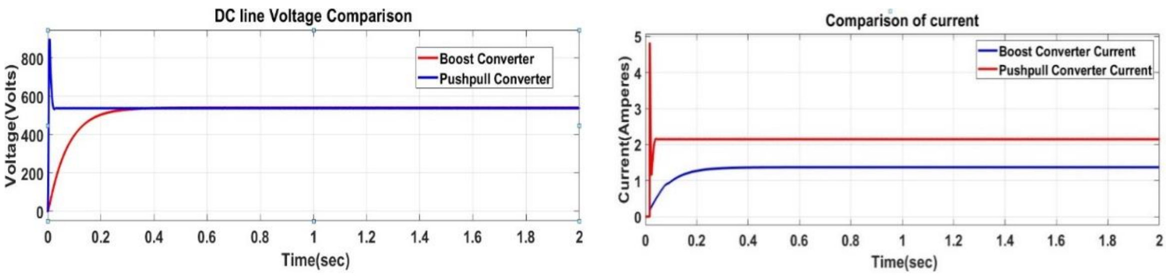


Figure 5. Model of SVPWM based solar powered AC motor drive

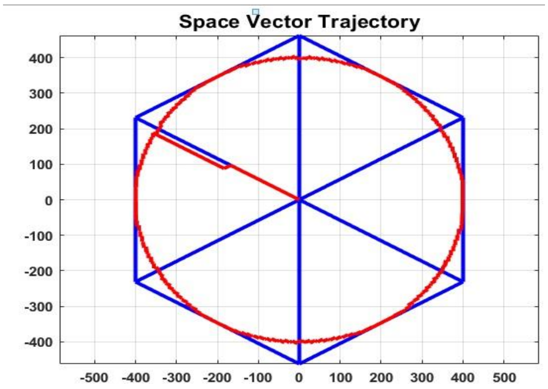
The comparison of boost converter current and push-pull converter current has been performed to demonstrate the latter is better in Figure 6. These two converters increase the value of voltage from 24 V to 600 V. As shown in Figure 6(a) the value of current for push-pull converter is 2.4 A while boost converter the value is 1.35 A. Figure 6(b) represent that reached the 600 V quickly as compared to boost converter. Simulation in MATLAB/Simulink has also been performed for comparison of the currents of both controllers.



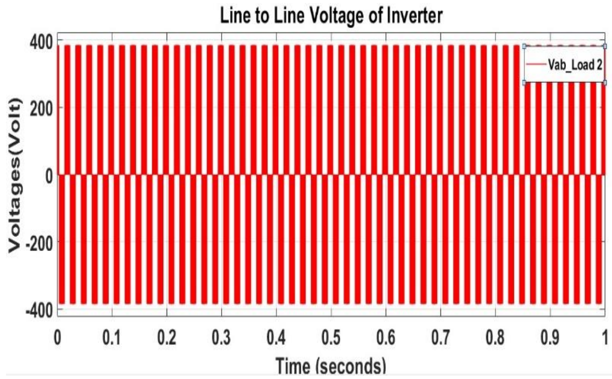
(a) (b)

Figure 6. Comparison of push-pull and boost converter; (a) comparison of the currents of the push-pull converter and boost converter and (b) comparison of voltages of push-pull and boost converter

The SVPWM inverter is implemented in MATLAB/Simulink. Figure 7(a) represents the trajectory of SVPWM. It represents the full utilization of voltage at each step and gives better efficiency than other PWM techniques. Figure 7(b) represents the line-to-line voltage at the load side which can be seen as a pure rectangular waveform of 380 V peak. Figure 8(a) represents voltages voltage of the batteries at the fully charged condition that is 32 V that is taken from the oscilloscope. Figure 8(b) represents the gate signal of 15 V from the gate driver circuit that is controlled by my RIO controller. These alternate signals are used for the operation of inverter switches. Figure 8(c) represents line-to-line output voltages of the three-phase inverter (i.e. 325 Vrms).

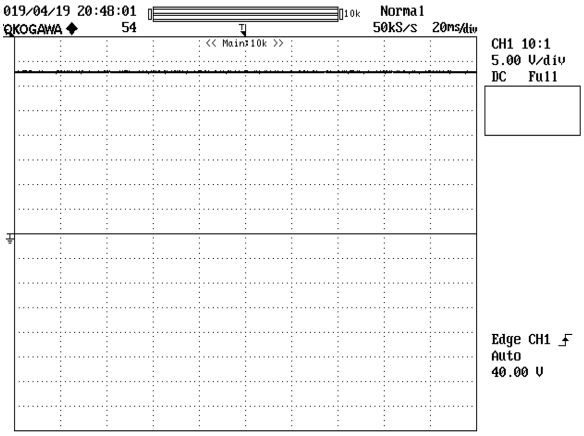


(a)

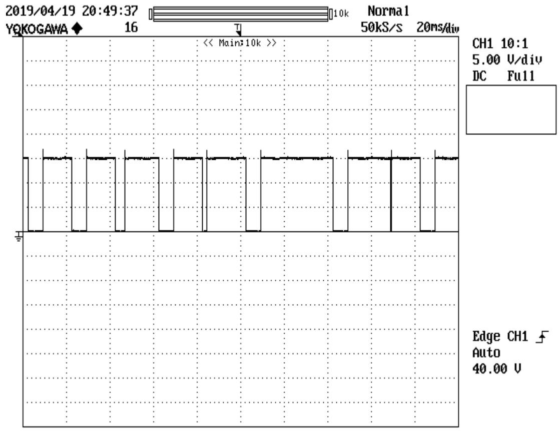


(b)

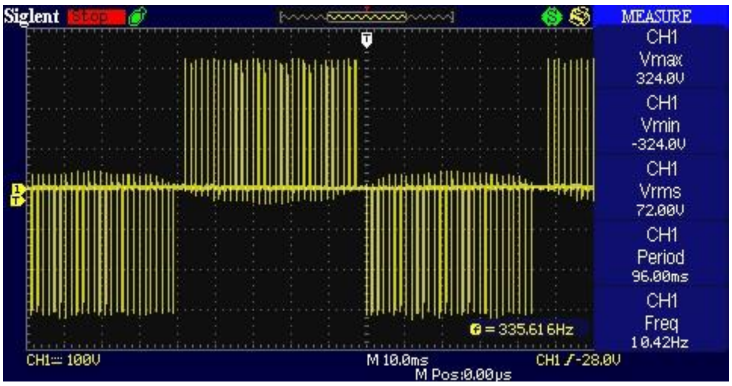
Figure 7. Metrices of SVPWM (a) space vector trajectory of SVPWM and (b) line to line voltage of the three-phase inverter



(a)



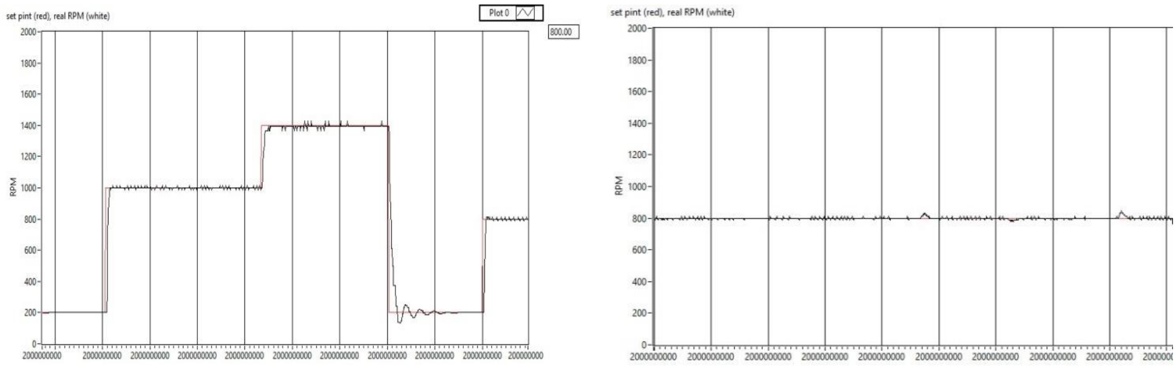
(b)



(c)

Figur 8. RIO based charge controller (a) voltages of batteries at fully charged condition, (b) gate driver signals for inverter switches, and (c) line to line voltage of the three-phase inverter

The motor rotates at variable speed with different rpm as shown in Figure 9(a). It represents that the motor rotates with different rpm without my RIO controller closed-loop system. PI controller is used to controlling the speed of the motor in a close feedback system for constant speed. This control has a change in frequency multiplier so that frequency remains constant but at the same time change in voltage keeps the flux remain constant to avoid the machine from saturation and heating issues. Figure 9(b) shows motor rotates at constant rpm of 800 controlled by the closed-loop feedback system with my RIO controller.



(a) (b)

Figure 9. Motor RPM (a) RPM of the motor without close loop and (b) RPM of the motor with close loop

4. CONCLUSION

The renewable energy sources are sustainable energy resources in contrast to power generation from prevalent declining fossils. Globally, the solar-powered electric system has opened new horizons of research in the field of power electronics linked with solar electric output for optimal performance. This paper proposes a my-RIO controller-based AC drive utilizing power from a solar electric system. The push-pull converter is implemented to achieve desired DC voltage level for fulfilling the current requirements of the inverter in an optimized fashion instead of the conventionally employed boost converter. The FPGA-based my-RIO controller proves to present better computational power and effectively controlled feedback for the AC drive system. The overall performance of the proposed scheme substantiates its use in the industry due to its capability of utilizing solar power and providing smooth control of the induction motor.

REFERENCES

[1] J. H. Seo, C. H. Choi and D. S. Hyun, "A new simplified space-vector PWM method for three-level inverters," *IEEE Transactions on Power Electronics*, vol. 16, no. 4, pp. 545-550, 2001, doi: 10.1109/63.931078.

[2] S. Wei, B. Wu, and Q. Wang, "An improved space vector PWM control algorithm for multilevel inverters," *The 4th International Power Electronics and Motion Control Conference*, 2004, vol. 3, pp. 1124–1129.

[3] H. Sathishkumar and S. S. Parthasarathy, "Space vector pulse width modulation for DC-AC converter," *Second International Conference on Science Technology Engineering and Management (ICONSTEM)*, 2016, pp. 310-314, doi: 10.1109/ICONSTEM.2016.7560968.

[4] A. R. Beig, G. Narayanan and V. T. Ranganathan, "Modified SVPWM Algorithm for Three Level VSI With Synchronized and Symmetrical Waveforms," *IEEE Transactions on Industrial Electronics*, vol. 54, no. 1, pp. 486-494, 2007, doi: 10.1109/TIE.2006.888801.

[5] Y. Deng, K. H. Teo, C. Duan, T. G. Habetler, and R. G. Harley, "A fast and generalized space vector modulation scheme for multilevel inverters," *IEEE Transactions on Power Electronics*, vol. 29, no. 10, pp. 5204-5217, 2014.

[6] K. K. Vinoth, P. A. Michael, J. P. John, and S. S. Kumar. "Simulation and comparison of SPWM and SVPWM control for three phase inverters," *ARPN journal of engineering and applied sciences*, vol. 5, no. 7, pp. 61-74, 2010.

[7] A. M. Wu, Jinwen Xiao, D. Markovic and S. R. Sanders, "Digital PWM control: application in voltage regulation modules," *30th Annual IEEE Power Electronics Specialists Conference. Record. (Cat. No.99CH36321)*, 1999, pp. 77-83 vol.1, doi: 10.1109/PESC.1999.788984.

[8] A. von Jouanne, P. Enjeti and W. Gray, "Application issues for PWM adjustable speed AC motor drives," *IEEE Industry Applications Magazine*, vol. 2, no. 5, pp. 10-18, 1996, doi: 10.1109/2943.532149.

[9] J. F. Chen and C. L. Chu, "Combination voltage-controlled and current-controlled PWM inverters for UPS parallel operation," *IEEE Transactions on power Electronics*, vol. 10, no. 5, pp.547-558, 1995.

[10] Y. Ito and S. Kawauchi, "Microprocessor based robust digital control for UPS with three-phase PWM inverter," *IEEE transactions on power electronics*, vol. 10, no. 2, pp.196-204, 1995.

[11] E. Cengelci, S. U. Sulistijo, B. O. Woo, P. Enjeti, R. Teoderescu and F. Blaabjerg, "A new medium-voltage PWM inverter topology for adjustable-speed drives," *IEEE Transactions on Industry Applications*, vol. 35, no. 3, pp. 628-637, 1999, doi: 10.1109/28.767014.

[12] A. Alwadie, "A concise review of control techniques for reliable and efficient control of induction motor," *International Journal of Power Electronics and Drive Systems*, vol. 9, no. 3, pp. 1124-1139, 2018, doi: 10.11591/ijpeds.v9.i3.pp1124-1139.

[13] N. A. M. Kamari, I. Musirin, Z. A. Hamid and M. H. M. Zaman, "Oscillatory stability prediction using pso based synchronizing and damping torque coefficients," *Bulletin of Electrical Engineering and Informatics*, vol. 7, no. 3, pp. 331-344, 2018, doi: 10.11591/eei.v7i3.961.

[14] Chinmayi and B. G. Shivaleelavathi, "Digital control of three-phase cascaded multilevel inverter using FPGA wavect tool," *International Journal of Power Electronics and Drive Systems*, vol. 9, no. 1, pp. 189-197, 2018, doi: 10.11591/ijpeds.v9n1.pp189-197.

[15] M. Khanfara, R. El Bachtiri, M. Boussetta and K. El Hammoumi, "A multicarrier PWM technique for five level inverter connected to the grid," *International Journal of Power Electronics and Drive Systems*, vol. 9, no. 4, pp. 1774-1783, 2018, doi:

10.11591/ijpeds.v9.i4.pp1774-1783.
[16] K. J. Sinu and G. Ranganathan, “A photo voltaic source fed novel boosting switched Z-source multilevel inverter,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 9, no. 1, pp. 20-23, 2018, doi: 10.11591/ijeecs.v9.i1.pp20-23.
[17] V. Meenakshi and S. Paramasivam, “Control strategy used in DFIG and PMSG based wind turbines: an overview,” *Journal of Power Electronics and Drive Systems*, vol. 8, no. 3, pp. 1160-1167, 2017, doi: 10.11591/ijpeds.v8i3.pp1160-1167.
[18] N. A. Rahim, M. F. M. Elias and W. P. Hew, “Transistor-Clamped H-Bridge Based Cascaded Multilevel Inverter With New Method of Capacitor Voltage Balancing,” *IEEE Transactions on Industrial Electronics*, vol. 60, no. 8, pp. 2943-2956, 2013, doi: 10.1109/TIE.2012.2200213.
[19] M. M. Ismail and A. F. Bendary, “FOPID controller based AC pump supplied from PV standalone source tuned using fuzzy logic type 2,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 4, no. 1, pp. 10-19, 2016, doi: 10.11591/ijeecs.v4.i1.pp10-19.
[20] R. Taleb and H. Saidi, “IRAMY inverter control for solar electric vehicle,” *International Journal of Power Electronics and Drive Systems*, vol. 7, no. 3, pp. 1012-1022, 2016, doi: 10.11591/ijpeds.v7.i3.pp1012-1022.
[21] M. M. Ismail, “Daily constant PV output power supplying AC pumps using batteries,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 2, no. 2, pp. 275-284, 2016, doi: 10.11591/ijeecs.v2.i2.pp275-284.
[22] H. Husin, S. Saat, Y. Yusop, Z. Ghani and S. K. Nguang, “Development of class D inverter for acoustics energy transfer implantable devices,” *International Journal of Power Electronics and Drive Systems*, vol. 7, no. 1, pp. 75-84, 2016.
[23] Z. B. Ibrahim, M. L. Hossain, I. B. Bugis, J. M. Lazi and N. M. Yaakop, “Comparative analysis of PWM techniques for three level diode clamped voltage source inverter,” *International Journal of Power Electronics and Drive Systems*, vol. 5, no. 1, pp. 15-23, 2014.
[24] O. Elbeji, Z. Boussada and M. B. Hamed, “Inverter control: Comparative study between SVM and PWM,” *International Conference on Green Energy Conversion Systems (GECS)*, pp. 1-6, 2017.
[25] Zulkifli, S. Aizam, M. N. Hussin, and A. S. Saad, “MATLAB-Arduino as a low-cost microcontroller for 3 phase inverters,” *IEEE Student Conference on Research and Development*, pp. 1-5, 2014.
[26] Ji. H. and Z. Y. Li, “Research and simulation of SVPWM algorithm based on BP neural network,” *Key Engineering Materials*, vol. 693, pp. 1391-1396, 2016.
[27] V. S. Niravadya, C. A. Sam and E. R. Samuel, “Photovoltaic Pumping System using SVPWM based Induction Motor Drive with a High Gain Converter,” *Second International Conference on Inventive Communication and Computational Technologies (ICICCT)*, 2018, pp. 1909-1914, doi: 10.1109/ICICCT.2018.8473119.
[28] D. Anamika and S. Virendra, “SVPWM Techniques Used for Controlling Three-Phase Induction Motor Energized by Renewable Energy Source,” *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, vol. 6, no. 2, pp. 809-820, 2017, doi: 10.15662/IJAREEIE.2017.0602017.
[29] Z. R. Rony, S. C. Das and M. Z. Rahman Khan, “Space Vector Modulated PWM Generation for Motor Control Systems,” *10th International Conference on Electrical and Computer Engineering (ICECE)*, 2018, pp. 149-152, doi: 10.1109/ICECE.2018.8636720.
[30] D. C. Quach, Q. Yin, Y. F. Shi and C. J. Zhou, “Design and Implementation of Three-phase SVPWM Inverter with 16-bit dsPIC,” *12th International Conference on Control, Automation, Robotics & Vision Guangzhou*, China, 5-7th December 2012 (ICARCV 2012).
[31] Asma, R. L. Naik, and J. H. Suresh, “Implementation of space vector pulse width modulation using Arduino,” *International Journal of Science and Research*, vol. 3, no. 7, pp. 1706-1710, 2014.

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