TELKOMNIKA Telecommunication, Computing, Electronics and Control
Vol. 18, No. 2, April 2020, pp. 977~984
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v18i2.14848

Three-level modified sine wave inverter equipped with online temperature monitoring system

Suroso, Ahmad Khafidz, Winasis, Hari Siswantoro
Department of Electrical Engineering, Jenderal Soedirman University, Indonesia

Article Info

Article history:

Received Aug 15, 2019
Revised Dec 30, 2019
Accepted Feb 11, 2020

Keywords:

Gating signals
Power inverter
Real time

ABSTRACT

Research and development on power converters are getting more interesting in recent years. It is also buttressed by rapid development in related fields, such as power semiconductor, digital advanced control, magnetic material and use of power converters in many sectors. In addition to the power quality matter, simplicity of inverter circuits is another notable aspect that should be considered toward economical feature. Adding the quantity of power switches will increase complexity of overall inverter circuits. This paper discusses a circuit configuration of three-level modified sine wave neutral point shorted power inverter which work converting dc power into ac power with less number of power switches. To improve the performance and feature of inverter circuits, the inverter was equipped with online temperature monitoring, and overheat protection based on internet of things. Adding online temperature monitoring system makes easier in monitoring of circuits to prevent the excessive faults of inverter. Some computer-based test data are shown and discussed. Furthermore, experiment results of the inverter prototype, and its online monitoring system are presented. Test outputs demonstrated that the proposed system worked properly generating a three-level modified sine wave voltage, with online temperature monitoring system.

This is an open access article under the CC BY-SA license.

Corresponding Author:

Suroso,
Department of Electrical Engineering,
Jenderal Soedirman University,
Purbalingga, Indonesia.
Email: suroso.te@unsoed.ac.id

1. INTRODUCTION

Power inverter is required when the available power is in the form of dc power, but the power load needs ac power. It proceeds a stable or unregulated dc voltage to be a controlled ac voltage with enormity, frequency, and phase angle that can be regulated to meet the load requirement [1-4]. Some applications of power inverter require a fixed low frequency output current, i.e. 50 Hz or 60 Hz, such as for utility power loads, and renewable energy conversion system [5-7]. However, other applications require higher frequency, and variable frequency operations such as in induction heating and ac motor drive systems [8, 9].

A modern power inverter circuits composed by some controlled circuits such as power IGBTs and power MOSFETs. Power IGBTs have merits related with their higher power capability, and ease in operation. Power MOSFETs give features such as higher speed switching operation, and low on resistance, hence they are suitable for high frequency operation [10, 11]. In order to construct higher power inverter, some power IGBTs or MOSFETs can be operated in series or parallel. Another strategy is by applying multilevel inverter circuit configurations such as cascaded H-bridge, diode clamped, flying capacitor and hybrid multilevel inverters [12-14]. However, circuit complexity is an important issue introduced by multilevel inverter circuits [15-20]. The more power switches, the more complicated gate drive circuits will be involved.

Conventional two level power inverter produces two level ac voltage waveform having large dv/dt value. It causes high stress to power switches and insulation. To address this issue, a three-level output voltage produced by three-level inverter circuits is able to reduce the gradient voltage and improve output waveform quality because of its less waveform distortion [21, 22]. In a three-level diode clamped inverter as depicted in Figure 1, four controlled power switches plus two power diodes are necessary to construct the power circuits [23-30]. The controlled power circuits of this inverter need four gate drive circuits with individual isolated power supply. The power diodes in this circuit will cause more power losses. Therefore, circuit complexity and power efficiency are problems that must be addressed in developing a new inverter circuits. In addition, in a modern power system, a real time monitoring system of inverter is an important aspect to ensure the inverter works well as required [31-33]. It is also needed to prevent the inverter circuits from fault that will disturb the power supply to the load [34-36]. As a result, the reliability of the system will increase.

This paper communicates and discusses a different circuit of three-level neutral point shorted (NPS) inverter. The circuit is able to establish a three-level voltage wave to the load with less number of controlled switches, simpler driving circuits, and their power supplies requirement. The design of the inverter circuits is shown and discussed. Moreover, a laboratory prototype of three-level NPS inverter equipped with online temperature monitoring system by using internet of things was constructed and tested in laboratory.

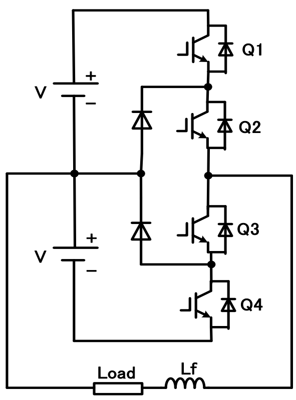


Figure 1. Three-level diode clamped inverter circuits [22-29]

2. PROPOSED INVERTER CIRCUITS

2.1. Circuit configuration

Figure 2 presents the proposed circuit of three-level NPS inverter. It is composed by three controlled power switches, four diodes with two dc voltage sources, V_{DC}. The IGBT switch Q3 and the four diodes formed a bidirectional power switch. It can block voltage in two directions, and it is also able to conduct current in two ways. The circuit demands three gate drive circuits, and three associated insulated gate drive power supplies, only. It is simpler than the three-level diode clamped inverter of Figure 1.

The operation principle of circuit is discribed in Table 1 and Figure 3. It generates a three-level voltage waveform as a modified sine waveform, i.e. +V, 0 and –V voltage levels. Positive level voltage +V is generated by ON state of switch Q1 and Q3. While the negative level voltage is produced when the switch Q2 and Q3 and are turned ON. The 0 level voltage is produced if switch Q3 is turned ON, while the Q1 and Q2 are at OFF state. Power diodes will conduct current if the switch Q3 is at ON condition. The more detail operation of inverter is presented in Figure 4. The power switch Q3 conducts current for 0 output voltage operation, only.

Table 1. Switching operation

Q1	Q2	Q3	Output Voltage
ON	OFF	OFF	+V
OFF	ON	OFF	-V
OFF	OFF	ON	0

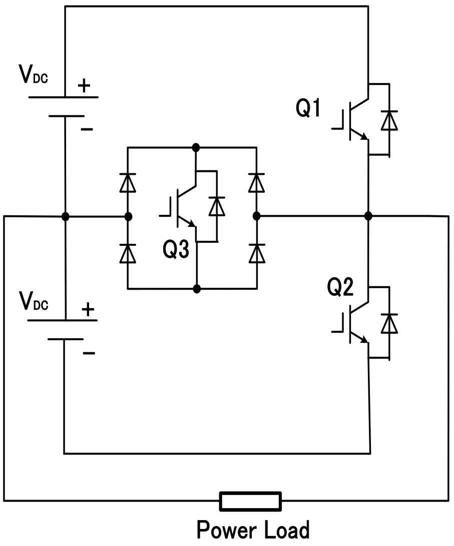


Figure 2. Proposed inverter circuits

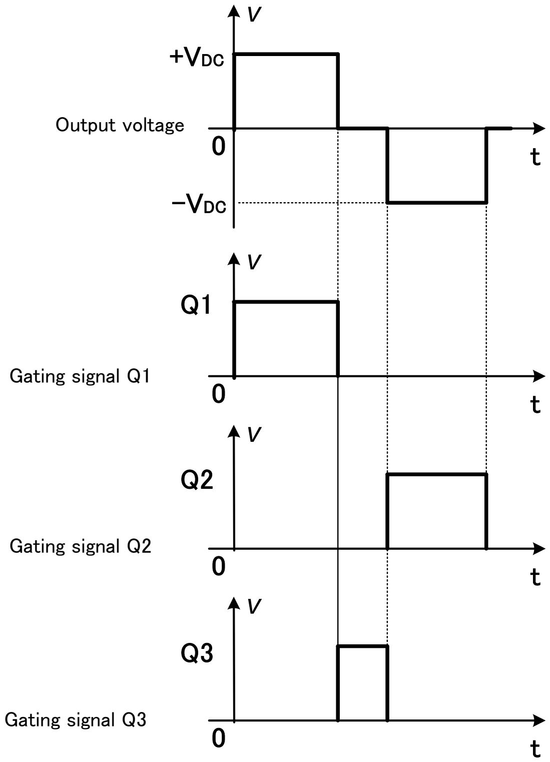
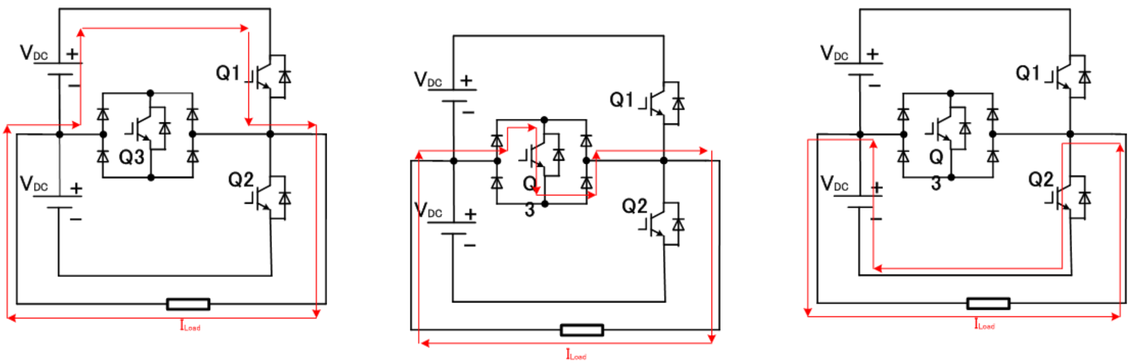


Figure 3. Operation modes of proposed inverter



(a) (b) (c)

Figure 4. Load current paths of inverter: (a) +V voltage, (b) 0 V voltage, (c) –V voltage

2.2. Design and materials of inverter prototype

A prototype of proposed inverter circuits was designed to operate in the modified sine wave operation. To generate control signals of inverter power switches, an arduino mega 2560 was implemented. The power inverter circuit was constructed by IGBT switches STGW40N120KD. While the gate drive circuit design using optocouplers TLP250 is presented in Figure 5. The optocouplers were supplied by three DCP020515. They were required to obtain insulated power supply for each optocoupler. Furthermore, temperature sensors DS18B20 were installed at the body of power IGBTs to sense its temperature during inverter's operation. It has capability with temperature operation range until 125°C. The wifi module ESP8266 was applied to build an online monitoring of power IGBT's temperature. To make display of the system a LCD (liquid crystal display) is applied.

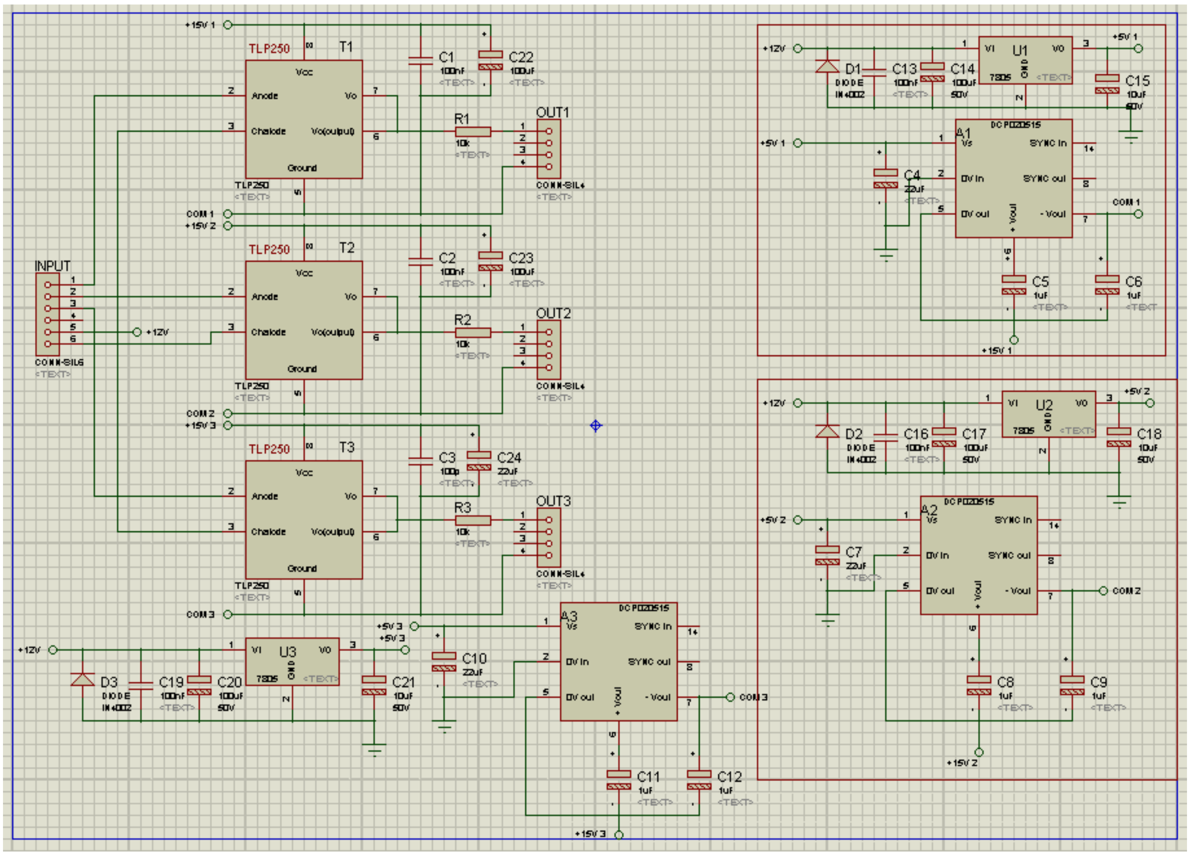
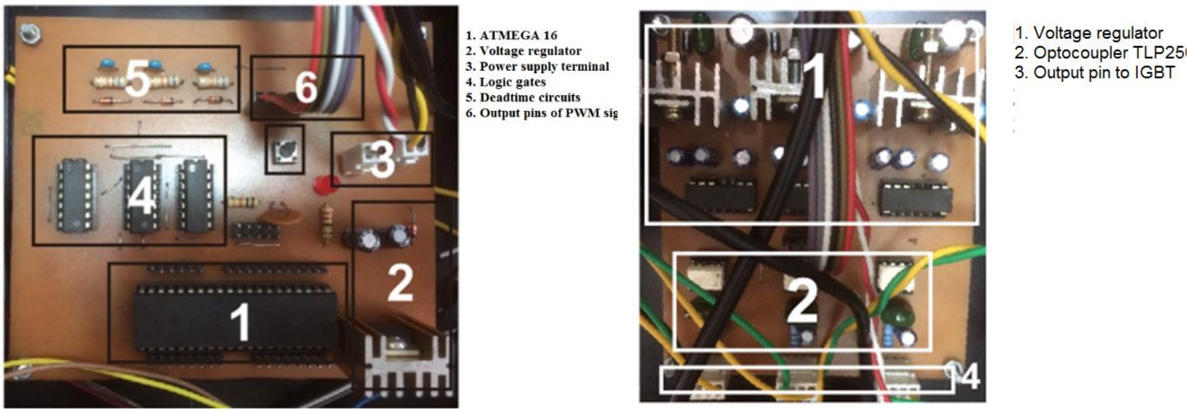


Figure 5. Design of driving circuits

2.3. Hardware implementation

The prototype of inverter with online temperature monitoring system was set up in laboratory. The gate drive signal generator of IGBT switch is imaged in Figure 6(a). While the gate drive circuits implemented optocoupler TLP250 is shown in Figure 6(b). Three opto-couplers with three insulated gate drive power supplies were used to drive three IGBT switches. While Figure 7 shows configuration of the developed online temperature monitoring system. The overall prototype of inverter system is displayed in Figure 8 including the power inverter circuits build using IGBT switches and power transformer. This transformer is employed to gain higher output voltage of inverter circuits to meet the load requirement.



(a) (b)

Figure 6. (a) Gating signal generator circuits; (b) Gate drive circuits

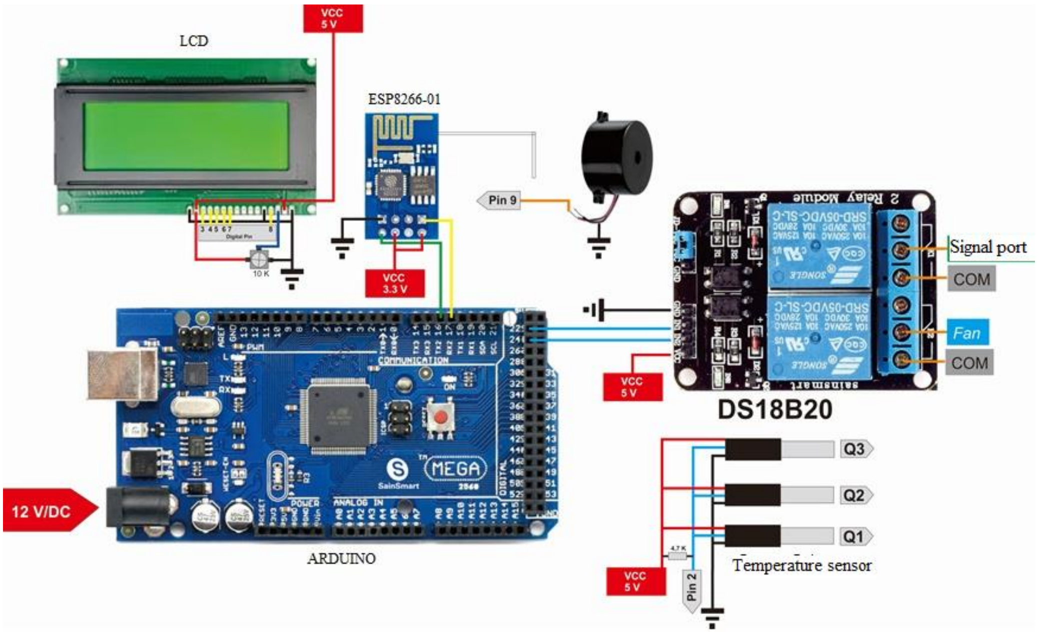


Figure 7. Online monitoring system of inverter power switches

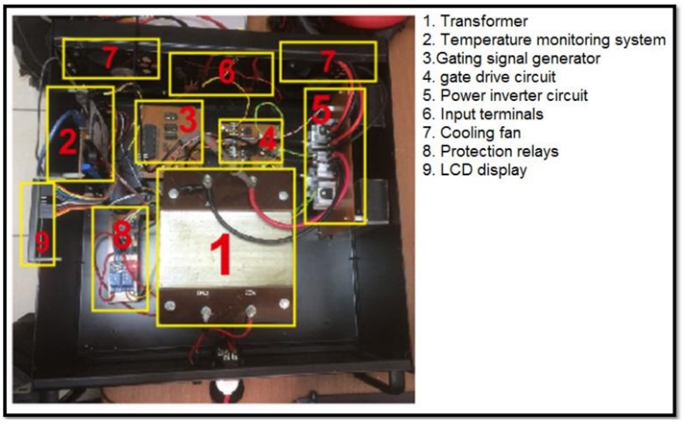


Figure 8. Overall inverter system

3. TEST RESULTS

Computer simulation tests were carried out to examine the developed inverter. The inverter circuit was connected with 24 V dc power source, resistor 10 Ω in series with inductor 5 mH. Fundamental frequency of ac current was set at 50 Hz. Figure 9 presents test result of inverter's output voltage and load current waveforms obtained using PSIM software. A three-level modified ac voltage was properly produced by inverter circuits. Moreover, experiments of prototype inverter system were carried out in laboratory. The gating signal circuits of inverter was tested. Figure 10 shows the waveforms of gating signals produced by microcontroller. The frequency of the first and second signals is 50 Hz that is the main output frequency of inverter, while the third signal frequency is 100 Hz. The third signal is required to create 0 level of ac output voltage waveform. The magnitudes of these signals is around 5 V. Furthermore, Figure 11 presents the gating signals after passing through gate drive circuits TLP250. The magnitude of these signals is about 15 V, which is high enough to make the power switch IGBTs operate "ON" and "OFF" properly. The inverter was connected to two regulated 12 V dc power supplies as input power of inverter circuit.

The output voltage of inverter circuits is shown in Figure 12. A three-level voltage, i.e. +12 V, 0 V, and -12 V, was produced well by the NPS inverter circuit. Furthermore, the online temperature monitoring system was examined to observe the temperature condition of inverter power switches. The results displayed by thingspeak is shown in Figure 13. A realtime and update temperature profile of inverter power switches at time range from 15.46 to 15.56 can be observed clearly. It will help in monitoring the operation condition of inverter, especially the temperature of inverter's switches which are very important to make power inverter operates properly.

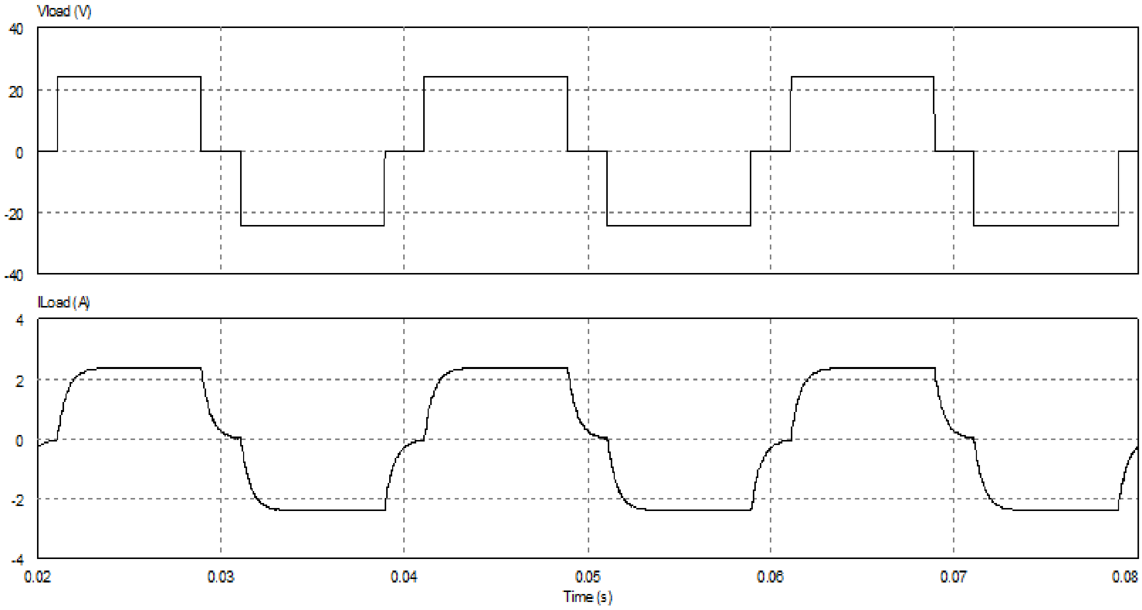
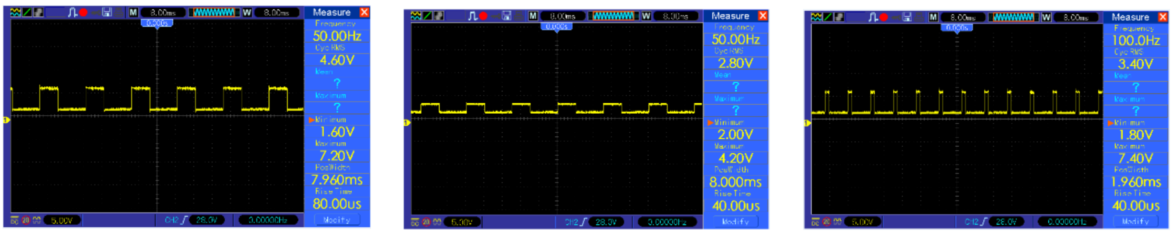
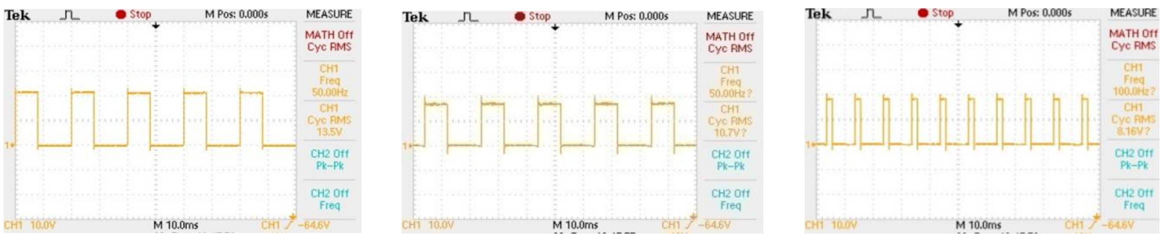


Figure 9. Output voltage and load current waveforms



(a) (b) (c)

Figure 10. Gating signals of inverter's switches: (a) gating signal Q1, (b) gating signal Q2, (c) gating signal Q3



(a) (b) (c)

Figure 11. Output signals of gate drive circuits TLP250: (a) gating signal of Q1, (b) gating signal of Q2, (c) gating signal of Q3

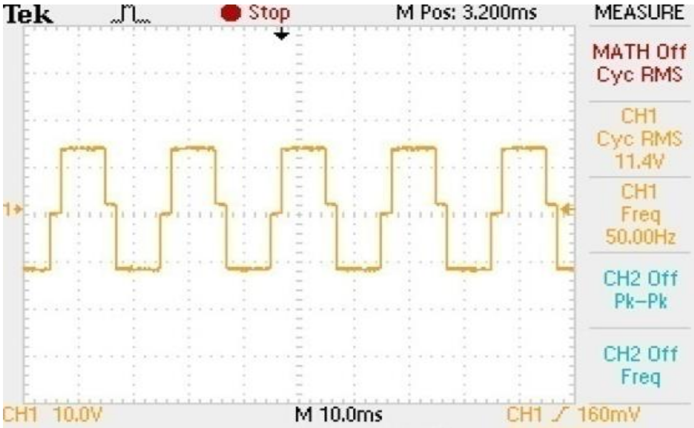


Figure 12. Output voltage of inverter

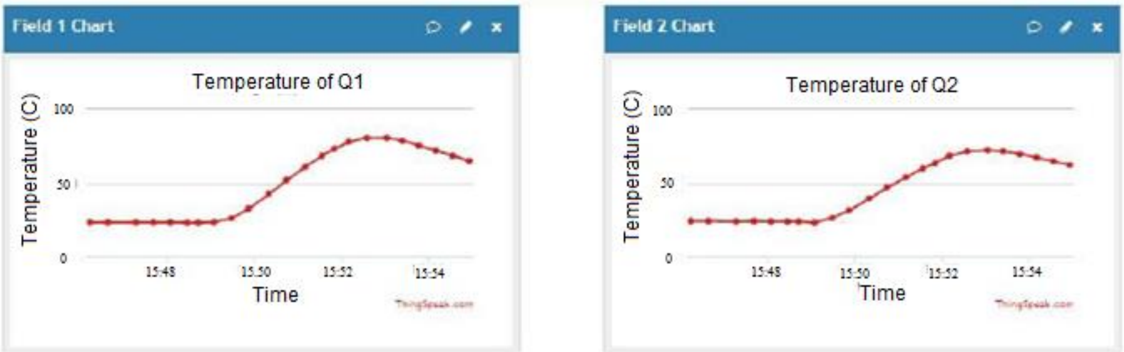


Figure 13. Online temperature monitoring results of switches Q1 and Q2

4. CONCLUSION

A simple circuit of three-level NPS voltage source inverter has been designed, tested and discussed in this paper. The new inverter can simplify circuit configuration of inverter by reducing the power devices and their control circuits compared to the conventional three-level diode clamped inverter. An online monitoring system of inverter's switches were designed and implemented to monitor the temperature of inverter's power switches. A laboratorium prototype of the inverter circuits and its online monitoring system was developed and tested in laboratory. The inverter circuits worked properly generated a modified sine wave three-level voltage waveform. Furthermore, the online monitoring system of inverter switches temperature was also confirmed worked well scanning the reatime temperature condition of inverter switches.

REFERENCES

[1] D. Ruiz-Caballero, et al., "Cascaded symmetrical hybrid multilevel DC-AC converter," *IEEE Energy Conversion Congress and Exposition (ECCE)*, pp. 4012-4019, 2010.

[2] M. Malinowski, et al., "A survey on cascaded multilevel inverters," *IEEE Transactions on Industrial Electronics*, vol. 57, no. 7, pp. 2197-2206, Jul 2010.

[3] R. S. Alishah and S. H. Hosseini, "A new multilevel inverter structure for high-power applications using multi-carrier PWM switching strategy," *International Journal of Power Electronics and Drive System (IJPEDS)*, vol. 6, no. 2, pp. 318-325, Jun 2015.

[4] Suroso, et al., "A different voltage-source power inverter with carrier based SPWM for open-end connection loads," *Energies*, vol. 12, no. 17, pp. 1-14, 2019.

[5] S. B. Kjaer, et al., "A review of single-phase grid-connected inverters for photovoltaic modules," *IEEE Transactions on Industrial Application*, vol. 41, no. 5, pp. 1292-1306, 2005.

[6] J. M. Carrasco, et al., "Power-electronics systems for the grid integration of renewable energy sources: a survey," *IEEE Transactions on Industrial Electronics*, vol. 53, no. 4, pp. 1002-1016, Jun 2006.

[7] Suroso, et al., "A battery-less grid connected photovoltaic power generation using five-level common-emitter current-source inverter," *International Journal of Power Electronics and Drive System (IJPEDS)*, vol. 4, no. 4, pp. 474-480, December 2014.
[8] G. Waltrich and I. Barbi, "Three-phase cascaded multilevel inverter using power cells with two inverter legs in series," *IEEE Transactions on Industrial Electronics*, vol. 57, no. 8, pp. 2605-2612, August 2010.
[9] K. Crorzine and Y. Familiant, "A new cascaded multilevel H-bridge Drive," *IEEE Transactions on Power Electronics*, vol. 17, no. 1, pp. 125-131, January 2002.
[10] Suroso and T. Noguchi, "Common-emitter topology of multilevel current-source pulse width modulation inverter with chopper-based DC current sources," *IET Power Electronics*, vol. 4, no. 7, pp. 759-766, August 2011.
[11] T. Noguchi and Suroso, "New topologies of multi-level power converter for use of next-generation ultra high-speed switching devices," *2009 IEEE Energy Conversion Congress & Exposition*, pp. 1968-1975, 2009.
[12] J. Rodiguez, et al., "Multilevel inverter: a survey of topologies, controls, and application," *IEEE Transactions on Industrial Electronics*, vol. 49, no. 4, pp. 724-738, August 2002.
[13] Suroso, et al., "Three-level common-emitter current-source power inverter with simplified dc current source generation," *Journal of Engineering Science and Technology*, vol. 13, no. 12, pp. 4027-4038, December 2018.
[14] Suroso, et al., "Five-level PWM inverter with a single DC power source for DC-AC power conversion," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 8, no. 3, pp. 1212-1219, Sep. 2017.
[15] G. Ceglia, et al., "A new simplified multilevel inverter topology for DC-AC conversion," *IEEE Transactions on Power Electronics*, vol. 21, no. 5, pp. 1311-1319, September 2006.
[16] Suroso, et al., "Simplified five-level voltage source inverter with level-phase-shifted carriers based modulation technique," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 13, no. 2, pp. 461-468, February 2019.
[17] E. Babaei, et al., "A single-phase cascaded multilevel inverter based on a new basic unit with reduced number of power switches," *IEEE Transactions on Industrial Electronics*, vol. 62, no. 2, pp. 922-929, February 2015.
[18] E. Babaei, "A cascade multilevel converter topology with reduced number of switches," *IEEE Transactions on Power Electronics*, vol. 23, no. 6, pp. 2657-2664, November 2008.
[19] Suroso, et al., "A different single phase hybrid five-level voltage source inverter using DC voltage modules," *TELKOMNIKA Telecommunication Computing Electronics and Control*, vol. 12, no. 3, pp. 557-562, Sep. 2014.
[20] N. Thombre, et al., "A novel topology of multilevel inverter with reduced number of switches and DC sources," *International Journal of Power Electronics and Drive System (IJPEDS)*, vol. 5, no. 1, pp. 56-62, June 2014.
[21] A. Ruderman, "About voltage total harmonic distortion for single and three-phase multilevel inverters," *IEEE Transactions on Industrial Electronics*, vol. 62, no. 3, pp. 1548-1551, March 2015.
[22] Y. Liu, et al., "Real-time calculation of switching angles minimizing THD for multilevel inverters with step modulation," *IEEE Transactions on Industrial Electronics*, vol. 56, no. 2, pp. 285-293, February 2009.
[23] J. Rodriguez, et al., "A survey on neutral-point-clamped inverters," *IEEE Transactions on Industrial Electronics*, vol. 57, no. 7, pp. 2219-2230, July 2010.
[24] A. Nabae, et al., "A new neutral-point-clamped PWM inverter," *IEEE Transactions on Industry Application*, vol. IA-17, no. 5, pp. 518-523, September 1981.
[25] X. Yuan and I. Barbi, "Fundamentals of a new diode clamping multilevel inverter," *IEEE Transactions on Power Electronics*, vol. 15, no. 4, pp. 711-718, July 2000.
[26] L. Zhou, et al., "Neutral-point-clamped circuits of single-phase PV inverters: generalized principle and implementation," *2015 IEEE Energy Conversion Congress and Exposition (ECCE)*, pp. 442-449, 2015.
[27] L. Masisi, et al., "A three level neutral point clamped (NPC) inverter synchronous reluctance machine (SynRM) drive," *IEEE Transactions on Industry Applications*, vol. 51, no. 6, pp. 4531-4540, 2015.
[28] L. Zhang, et al., "A family of neutral point clamped full-bridge topologies for transformerless photovoltaic grid-tied inverters," *IEEE Transactions on Power Electronics*, vol. 28, no. 2, pp. 730-739, February 2013.
[29] G. Yue, et al., "Research on three-level neutral point clamped inverter in photovoltaic power generation technology," *10th International Conference on Intelligent Human-Machine Systems and Cybernetics (IHMSC)*, pp. 31-34, 2018.
[30] Y. Yang, et al., "Fast finite-switching-state model predictive control method without weighting factors for T-type three-level three-phase inverters," *IEEE Transactions on Industrial Informatics*, vol. 15, no. 3, pp. 1298-1310, March 2019.
[31] I. M. Moreno-Garcia, et al., "Real-time monitoring system for a utility-scale photovoltaic power plant," *Sensors*, vol. 16, no. 6, pp. 1-25, May 2016.
[32] I. M. Moreno-Garcia, et al., "Performance monitoring of a solar photovoltaic power plant using an advanced real-time system," *16th International Conference on Environment and Electrical Engineering (EEEIC)*, pp. 1-6, 2016.
[33] F. Shariff, et al., "Zigbee-based data acquisition system for online monitoring of grid-connected photovoltaic system," *Expert Systems with Applications*, vol. 42, no. 3, pp. 1730-1742, February 2015.
[34] W. Chine, et al., "Fault detection method for grid-connected photovoltaic plants," *Renewable Energy*, vol. 66, pp. 99-110, June 2014.
[35] F. Khater, et al., "Fault diagnostics in an inverter feeding an induction motor using fuzzy logic," *Journal of Electrical Systems and Information Technology*, vol. 4, no. 1, pp. 10-17, May 2017.
[36] A. B. M. Oliveira, et al., "Short-circuit fault diagnosis based on rough sets theory for a single-phase inverter," *IEEE Transactions on Power Electronics*, vol. 34, no. 5, pp. 4747-4764, May 2019.