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MULTILEVEL INVERTER SIMULATION 9 LEVEL H-BRIDGE TOPOLOGY WITH HYSTERESIS CONTROL

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Abstract

Inverter is an electronic circuit to convert DC power source into AC. In general, the inverter will produce a relatively large Total Harmonic Distortion (THD) value so that it will result in damage to electronic devices, to minimize this, a multilevel inverter is made which can reduce the THD value by increasing the level using the switching method. In this research a 9-level cascaded H-Bridge topology cascaded H-Bridge topology simulation is designed to identify the output of this multilevel inverter. The addition of R, RL, RC, RLC, and induction motor loads affects the THD value. To calculate THD, we use Fast Fourier Transfer (FFT) on MATLAB Simulink. The no-load test results produced a THDv of 13.90%. In the R load test the resulting THDv and THDi values were 13.91%. In the RL load test it produces a THDv value of 13.91%, and a THDi of 0.2% to 0.12%. In the RC load test it produces a THDv value of 13.91% to 13.85%, and a THDi of 15.55% to 70.53%. The RLC load test produced a THDv value of 13.91% and the lowest THDi was 0.06%. In the load test, the induction motor produces a THDv value of 13.91% to 13.92%, and a THDi of 0.88% to 0.25%.

Keywords: *Cascaded H-Bridge, Hysteresis,* Multilevel Inverter, THD

I. INTRODUCTION

Electronic equipment that is increasingly developing, one of the tools that is often used to provide electrical energy, is the battery. The battery is a device that can generate electrical energy by transferring electrons between the anode and cathode [1]. However, the electricity generated from this battery is DC (Direct Current) electricity. Inverter is a converter that functions to convert DC input voltage to AC output voltage with a certain value and frequency [2]. Multilevel Inverter is a converter that is used to convert DC input electricity into AC output electricity, where the resulting output has more than 2 or more levels of voltage and current [3]. Hysteresis control is an on/off control system in a range of values between the switch displacement reference limits, the value between the reference and the upper and lower limits is the tolerance allowed when the output is at the reference value [4].

Harmonics are disturbances that occur due to distortion of current and voltage waves, causing the resulting wave to not be sinusoidal. The harmonic standard used in electric power systems is the IEEE 519-2014 standard, namely THD (*Total Harmonic Distortion)* [5].

The inverter has a working principle, namely using electronic switching to produce an output waveform in the form of a sine wave. As a result of electronic switching in the inverter, the output waveform is distorted and also creates harmonics. The resulting harmonics will cause the output power on the inverter to experience losses and can also cause damage to the equipment [6].

II. LITERATURE REVIEW

A. Inverter

Inverter is an electronic device that can convert DC electricity into AC electricity whose output voltage can be adjusted. The input voltage source can use a battery, solar cell, or other DC voltage source [3].

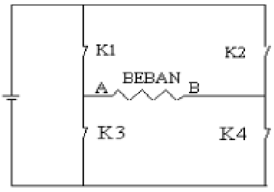

Fig 1. *Full-Bridge* Inverter Circuit

B. Multilevel Inverter

Multilevel Inverter is a concept to produce an AC signal output that does not only depend on two voltage levels. Several voltage levels can be added to produce a smoother and nearly sinusoidal output waveform by producing low harmonic distortion values so that the resulting power quality is better.

C. IGBT

IGBT is a transistor device that can be used as a power switch. IGBTs combine the advantages of MOSFETs and BJTs, have a high input impedance like MOSFETs, and low state conduction losses like BJTs. The control terminal is a gate. IGBT has an alternative PNPN 4 layer structure, which can lock like a thyristor provided (αnpn + αpnp) > 1 [7].

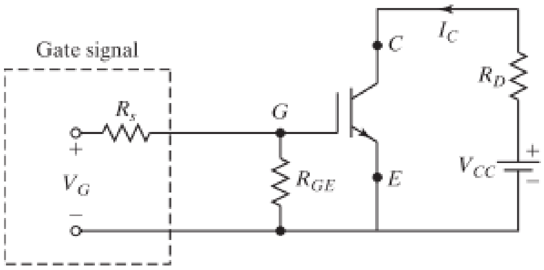

Fig 2. IGBT Circuit

D. *Hysteresis* Control

Hysteresis control is a current control technique which enables the switching of the connected phase voltages as a result of the current sensor feedback form [8].

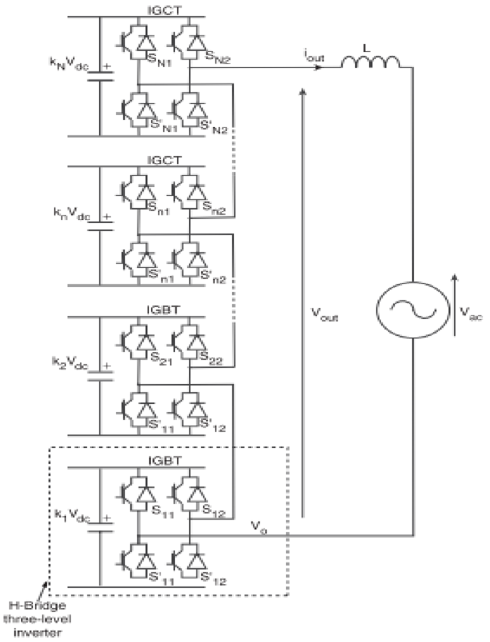

Fig 3. Configuration of Multilevel Cascaded H-Bridge Inverters

For example, Fig 3. shows the topology of a three-level H bridge inverter and how several H-Bridges can be connected in series to implement a hybrid (cascaded) inverter. The output voltage Vo from a single H-Bridge inverter can only switch between the three voltage levels +Vdc,0, and –Vdc. But when connected in series, the Vo output of the hybrid inverter can switch between voltage levels by a greater number, thereby increasing the quality of the waveform.

E. Harmonics

Harmonics are disturbances in the electric power system caused by the distortion of current and voltage waves, causing the formation of waves that are not sinusoidal and cause wave defects. [9].

The value of harmonics in the electric power system is expressed in Total Harmonic Distortion (THD) according to (1) and (2).

- Total Harmonic Distortion (THD) Current :

$$THDi = \frac{\sqrt{\sum_{2}^{\infty} I_n^2}}{I1} X\ 100\% \quad (1)$$

- Total Harmonic Distortion (THD) Voltage :

$$THDv = \frac{\sqrt{\sum_{2}^{\infty} V_n^2}}{V1} X\ 100\% \quad (2)$$

F. Electrical Load

A tool that can work or function by utilizing electrical energy is called an electric load. Electrical loads can be divided into 3 based on their nature, namely: resistive loads, inductive loads, capacitive loads.

1) Resistive Loads

Resistive loads are electrical loads on AC power circuits caused by purely resistive electrical equipment such as heating elements and incandescent lamps.

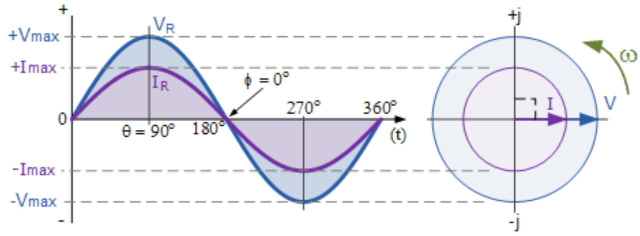

Fig 4. Sinusoidal Wave Resistive Load and Phasor Diagram

2) Inductive Loads

Inductive loads are loads generated by wire coils found in various devices such as transformers, motors. Coils are needed by these tools to produce a magnetic field as a working component.

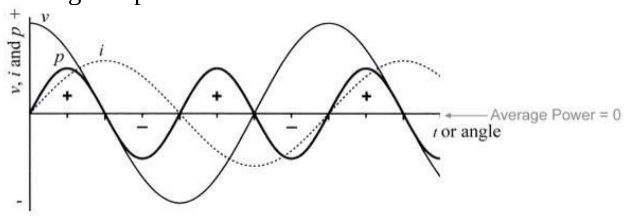

Fig 5. Inductive Load Sinusoidal Wave

3) Capacitive Loads

A capacitive load is the opposite of an inductive load, if the inductive load prevents changes in the value of the AC electric current, then the capacitive load has the property of blocking changes in the value of the electric voltage. This property shows as if the capacitor stores voltage temporarily.

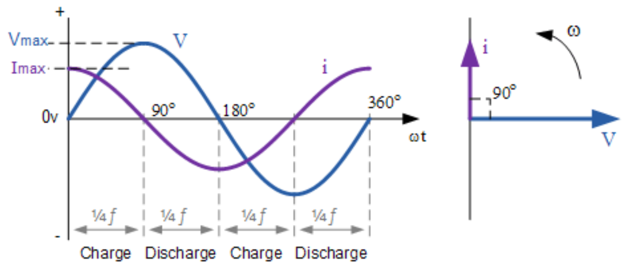

Fig 6. Sinusoidal Waves of Capacitive Loads and Phasor Diagrams

4) Induction Motor

Motor is a tool to convert electrical energy into mechanical energy. Electric motors are widely used in various household and industrial applications and what is often used is the AC motor. AC motors are divided into 2 types, namely, 1-phase induction motors (household equipment) and 3-phase (industrial equipment) [10].

III. Methods

Fig 7. Shows the control block diagram for controlling the output on a multilevel inverter.

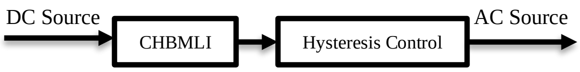

Fig 7. Control block diagram

A DC input source of 311 V is inserted, then flowed to CHBMLI (Cascaded H-Bridge Multilevel Inverter) on the 4 IGBT power switches in each H-Bridge and a switching process occurs to produce a multilevel voltage level. The 4 IGBT power switches in each H-Bridge are controlled and connected using the from and go to functions which are connected to the hysteresis control which is used to regulate the Switching process on the IGBT and produce output in the form of a multilevel AC voltage level that is close to sinusoidal with a THD value The low one.

IV. Results and Discussion

A. Simulation Results

1) No-Load Testing

Tbl 1. No-Load Test Results for THD

THDv	13,90 %
THDi	0

Tbl 1. Shows the results of a 9-level no-load multilevel inverter test. It can be seen that the resulting THD is 13.90% for THDv and 0% for THDi.

2) Testing With R Load

Tbl 2. Test Results With R Load Against THD

Experiment	R	THDv	THDi
1	5	13,91%	13,91%
2	10	13,91%	13,91%
3	15	13,91%	13,91%
4	20	13,91%	13,91%
5	25	13,91%	13,91%
6	30	13,91%	13,91%
7	35	13,91%	13,91%
8	40	13,91%	13,91%
9	45	13,91%	13,91%
10	50	13,91%	13,91%

Tbl 2. Shows the results of a 9-level multilevel inverter test using a load R. It can be seen that the test results with a load R yield a THDv and THDi value of 13.91%.

3) Testing With RL Load

Tbl 3. Test Results With RL Load Against THD

Experiment	QL	THDv	THDi
1	500	13,91%	0,2 %
2	1000	13,91%	0,14 %
3	1500	13,91%	0,12 %
4	2000	13,91%	0,11 %
5	2500	13,91%	0,11 %
6	3000	13,91%	0,11 %
7	3500	13,91%	0,1 %
8	4000	13,91%	0,11 %
9	4500	13,91%	0,11 %
10	5000	13,91%	0,12 %

Tbl 3. Shows the results of a 9-level inverter multilevel test using an RL load. It can be seen that the test results with RL loads produce a THDv value of 13.91% and the THDi value has decreased from 0.2% to 0.12%.

4) Testing With RC Loads

Tbl 4. Test Results With RC Load Against THD

Experiment	QC	THDv	THDi
1	500	13,91 %	15,55 %
2	1000	13,90 %	19,66 %
3	1500	13,90 %	25,05 %
4	2000	13,90 %	31,06 %
5	2500	13,89 %	37,39 %
6	3000	13,89 %	43,88 %
7	3500	13,88 %	50,48 %
8	4000	13,87 %	57,13 %
9	4500	13,86 %	63,82 %
10	5000	13,85 %	70,53 %

Tbl 4. Shows the results of a 9-level inverter multilevel test using an RC load. It can be seen that the test results with the RC load, the THDv value has decreased from 13.91% to 13.85% and the THDi value has increased from 15.55% to 70.53%.

5) RLC Load Testing

Tbl 5. Test Results With RLC Load Against THD

Experiment	QL	QC	THDv	THDi
1	500	4500	13,91 %	0,9 %
2	1000	4000	13,91 %	0,47 %
3	1500	3500	13,91 %	0,21 %
4	2000	3000	13,91 %	0,08 %
5	2500	2500	13,91 %	0,06 %
6	3000	2000	13,91 %	0,1 %
7	3500	1500	13,91 %	0,16 %
8	4000	1000	13,91 %	0,73 %
9	4500	500	13,91 %	0,89 %

Tbl 5. Shows the results of a 9-level inverter multilevel test using an RLC load. It can be seen that the test results with the RLC load yielded a THDv value of 13.91% and the lowest THDi of 0.06%.

6) Testing With Induction Motor Load

Tbl 6. Test Results With Induction Motor Load Against THD

Experiment	Tm	THDv	THDi
1	0,5	13,91 %	0,88 %
2	1	13,91 %	0,87 %
3	1,5	13,91 %	0,86 %
4	2	13,91 %	0,86 %
5	2,5	13,91 %	0,85 %
6	3	13,92 %	0,32 %
7	3,5	13,92 %	0,3 %
8	4	13,92 %	0,28 %
9	4,5	13,92 %	0,27 %
10	5	13,92 %	0,25 %

Tbl 6. Shows the results of a 9-level multilevel inverter test using an induction motor load. It can be seen that the test results with an induction motor load, the THDv value has increased from 13.91% to 13.92% and the THDi value has decreased from 0.88% to 0.25%.

B. Graph of Simulation Results

1) Testing With Load R

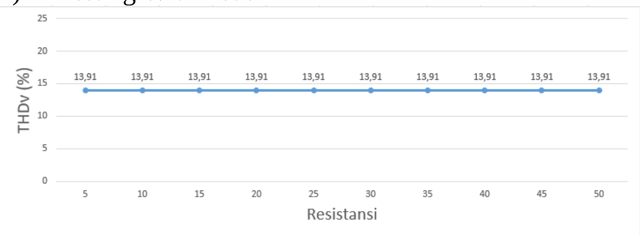

Fig. 8. Graph of R Load Test Results for THDv

Fig 8. shows a graph regarding the results of testing the addition of R load to THDv. From the picture above it can be explained that the THDv value is fixed and does not change, which is equal to 13.91%, which means that the addition of the load R does not affect the amount of THDv.

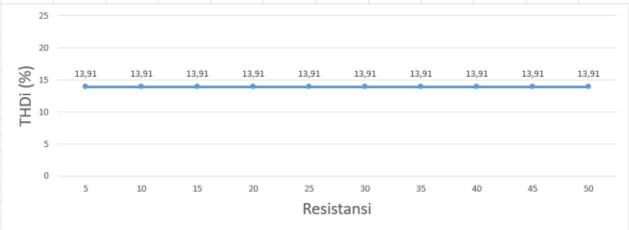

Fig. 9. Graph of R Load Test Results Against THDi

Fig 9. shows a graph regarding the results of testing the addition of load R to THDi. From the picture above it can be explained that the THDi value is constant and does not change, which is equal to 13.91%, which means that the additional load R does not affect the value of THDi.

2) Testing With RL Loads

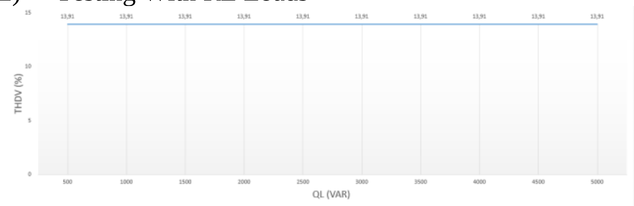

Fig. 10. Graph of RL Load Test Results Against THDv

Fig 10. shows a graph regarding the results of testing the addition of the RL load to THDv. From the picture above it can be explained that changes in the value of the RL load have no effect on THDv, because the THDv value is fixed and does not change at 13.91%.

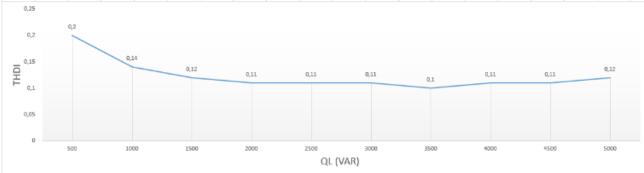

Fig 11. Graph of RL Load Test Results Against THDi

Fig 11. shows a graph regarding the results of testing the addition of the RL load to THDi. From the picture above it can be explained that with an increase in the RL load, it affects the amount of THDi. The THDi value will decrease as the RL load value increases, from 0.2% to 0.12%.

3) Testing With RC Loads

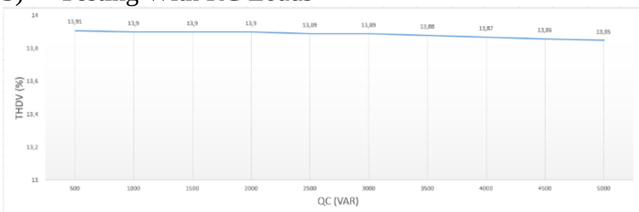

Fig. 12. Graph of RC Load Test Results Against THDv

Fig 12. shows a graph regarding the results of testing the addition of the RC load to THDv. From the picture above it can be explained that changes in the value of the RC load greatly affect THDv. It can be seen that by increasing the value of the RC load, the THDv value will decrease from 13.91% to 13.85%.

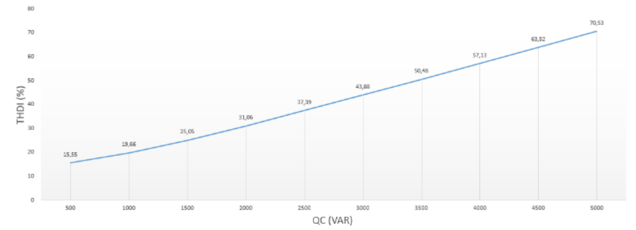

Fig 13. Graph of RC Load Test Results Against THDi

Fig 13. shows a graph regarding the results of testing the addition of the RC load to THDi. From the picture above, it can be explained that increasing the RC load affects the amount of THDi. The greater the value of the RC load, the greater the THDi value will be and increase from 15.55% to 70.53%.

4) RLC Load Testing

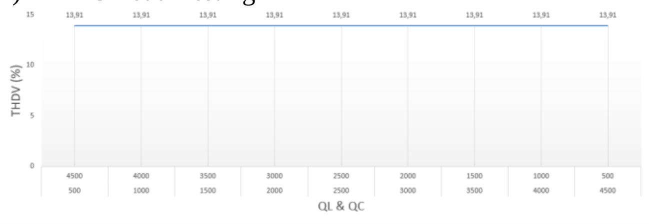

Fig. 14. Graph of RLC Load Test Results Against THDv

Fig 14. shows a graph regarding the test results of increasing the RLC load on THDv. From the picture above it can be explained that changing the value of the RLC load has no effect on THDv. It can be seen that the THDv value is constant and does not change even though the RL and RC loads change each other, namely 13.91%.

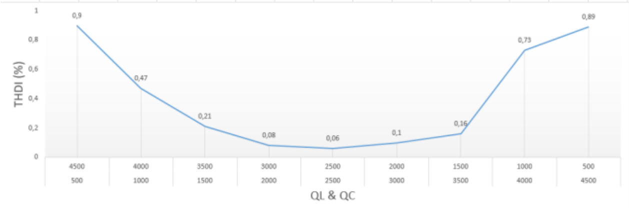

Fig 15. Graph of RLC Load Test Results Against THDi

Fig 15. shows a graph regarding the results of testing the addition of the RLC load to THDi. From the picture above it can be explained that changes in the value of the RLC load greatly affect THDi. It can be seen that the largest THDi value is when the QC 4500 and QL 500 values are 0.90%. The smallest THDi value occurs when the QL and QC values are balanced, which is 0.06%. The THDi value will gradually increase as the QL and QC values increase. But the increase in THDi values is greater when the QC value is greater than QL, compared to the QL value which is greater than QC.

5) Testing With Induction Motor Load

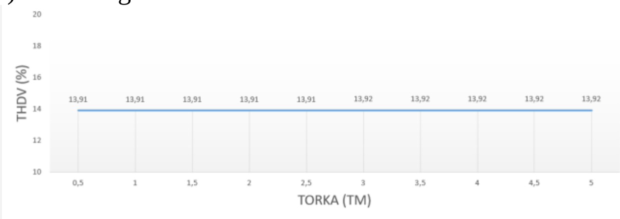

Fig 16. Graph of Induction Motor Load Test Results Against THDv

Fig 16. shows a graph regarding the results of testing the addition of an induction motor load to THDv. From the picture above it can be explained that changes in the value of the induction motor load affect THDv. The THDv value will be constant until the Tm = 2.5 Nm value is 13.91%, but when it is at the Tm = 3 Nm value, the THDv value will increase until the THDv value becomes 13.92%.

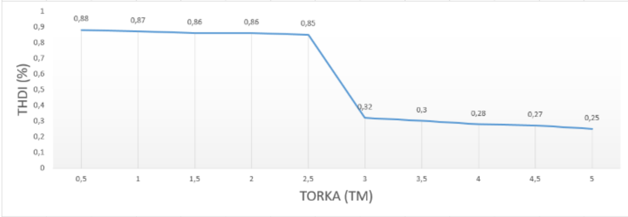

Fig. 17. Graph of Induction Motor Load Test Results Against THDi

Fig 17. shows a graph regarding the results of testing the addition of an induction motor load to THDi. From the picture above it can be explained that changes in the value of the induction motor load greatly affect THDi. The THDi value will gradually decrease as the load value Tm increases until the value Tm = 2.5 Nm, from 0.88% to 0.85%. Then when the Tm value = 3 Nm the THDi value will experience a very drastic decrease to 0.32%, and after that it will again decrease to 0.25%.

V. CONCLUSION

The result of the design of a 9-level H-Bridge topology multilevel inverter with hysteresis control using the Matlab simulink application, with an input voltage of DC 311 V. The multilevel inverter is controlled by an IGBT leg which functions as a switch used to connect the positive and negative parts of the DC-link to the load. The control used is hysteresis control which functions to control the waveform by comparing the reference wave with the carrier wave.

The simulation results on a no-load 9-level multilevel inverter are THDv of 13.90%. Meanwhile, the resulting current is 0 A and THDi is 0%, because there is no load attached to the multilevel inverter.

When the multilevel inverter is loaded with R, the THDv and THDi output values are the same and do not change, namely 13.91%. When given a load, the RL will reduce the THDi value from 0.2% to 0.12% but the THDv value does not change, which is 13.91%. And when given an RC load it will increase the THDi value from 15.55% to 70.53% but reduce the THDv value from 13.91% to 13.85%. When the RL and RC load values are added the lowest THDi will be produced when the RL and RC loads are balanced, which is 0.06%. The THDi value will gradually increase again as the RL load increases and the RC load decreases and vice versa, but the increase that occurs when the RL load is greater than the RC is not as large as when the RC load is greater RL. Meanwhile, THDv did not change, which was 13.91%. When the torque load (Tm) is added to the induction motor load, the THDv value will increase in value when the value of Tm = 3 Nm from 13.91% to 13.92%, while for THDi it will decrease in value from 0.88% to 0.25 %.

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Biography

Iqbal Fawzi Wisnu, I was born in Jakarta, on February 22, 2000, I studied in the Electrical Engineering Department, Faculty of Engineering, Siliwangi University, with a concentration in control systems