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Design of Speed Control System in Electric Car with Three Phase Induction Motor Propulsion

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Abstract: VFD (Variable Frequence Drive) can control the motor starting from when the motor is turned on until the motor is turned off, which is an advantage that other motor starting methods do not have. So that users can adjust motor control via VSD starting from regulating motor rotation, setting motor rotation, and others. In this study, the VFD type TOSVERT VF-S15-2015PM-W was used as a three-phase induction motor speed controller in an electric car prototype drive system. The system made is also equipped with a speed sensor to monitor the speed of the car. The sensor used is a KY 003 type sensor that uses the hall effect working principle. From the results of tests carried out on a three-phase induction motor, the results show that the speed, voltage, and power of the three-phase induction motor are directly proportional to the operating frequency set on the VFD.

Keywords: VFD, Electric Vehicle, Hall effect sensor

1. Introduction

Air pollution by various technologies that produce carbon dioxide emissions such as motor vehicles and factories has damaged the ozone layer system which in turn causes global warming. Global warming is an event of the process of increasing the average temperature in the atmosphere layer and the earth's surface caused by an increase in the concentration of greenhouse gases [1]. The government's effort to reduce the increase in air pollution is by issuing Presidential Regulation No. 55 of 2019. "That in order to increase energy efficiency, energy security and energy conservation in the transportation sector, and to realize clean energy, clean and environmentally friendly air quality, as well as Indonesia's commitment to reduce greenhouse gas emissions, it is necessary to accelerate the battery-based electric motor vehicle program. (battery electric vehicle) for road transportation "[2].

For an electric car to work properly, it must have a mechanical and electronic system. The mechanical system is a system related to the chassis, gas system and braking. An electronic system is a system related to supporting the movement of an electric car, displaying information using an LCD display [3]. An induction motor as a source of driving an electric car has advantages over other types of electric motors, including strong and simple construction, lower prices, high efficiency in normal circumstances and does not require difficult maintenance [4]. Three-phase induction motors use alternating current and require a stable three-phase voltage supply in the process [5].

2. Research Methods

2.1 Electric Car Mechanical System Design

In an electric car, a chassis frame that functions as a support for all loads on the vehicle is needed. For a chassis construction, the chassis itself must have strength, light weight and flexibility. The frame is a structure whose ends are rigidly joined (welded). All rods which are rigidly connected (fixed) are able to withstand axial forces, normal forces and moments. While the chassis itself consists of the frame, engine, power transfer, steering system, suspension system, brake system and other accessories.

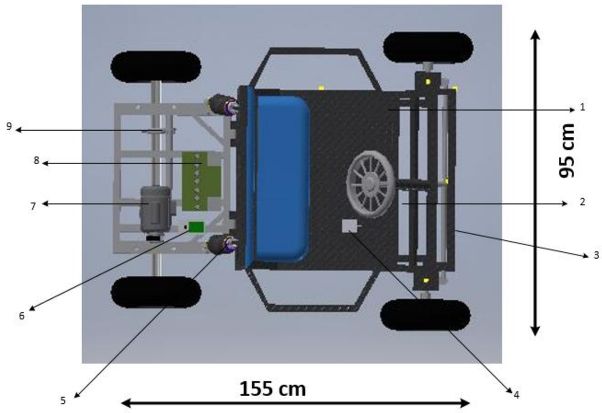

Figure 1: 3D Chassis Model Design

Information :
1. Brake Pedals.
2. Steering panel, contains a series of steering, monitoring system.
3. TOSVERT PWM inverter.
4. Gas pedal (potentio application as a frequency regulator).
5. Double Shockbreaker.
6. DC to AC inverter, functions to convert DC 12 V to AC 220 V from the accumulator.
7. 3-phase induction motor coupled to the axle using a chain.
8. Accumulator 12 V 65 Ah.
9. Disc brake.

2.2 Speed Control System Design

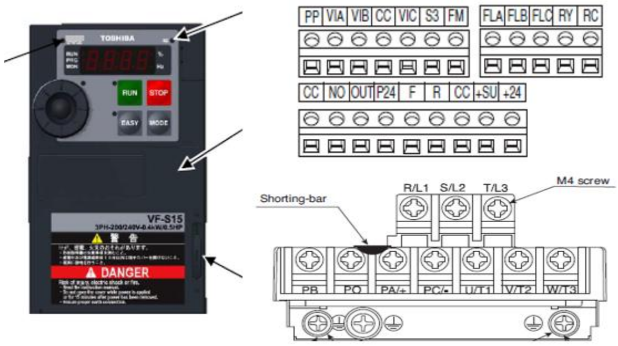

Figure 2: The Motor Connection Terminal

On the front display there is an LED display for displaying parameters on the inverter, as well as a dial setting to change the desired parameter by shifting right and left. The terminals on the inverter are divided into 2 groups, the power circuit terminals and the control circuit terminals. The power circuit terminal contains both single-phase and three-phase power supply input terminals, the grounding terminal, and the output terminals to the three-phase motor which are the functions of each terminal [6].

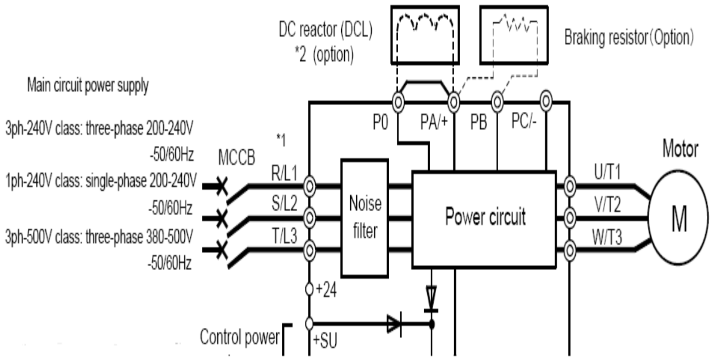

Figure 3: Motor Connection Circuit

At the power circuit terminal there are 2 input options, namely 1 phase and 3 phase. For 1-phase input, the terminals that can be used are R / L1 and S / L2, while T / L3 does not support use with a single phase source.

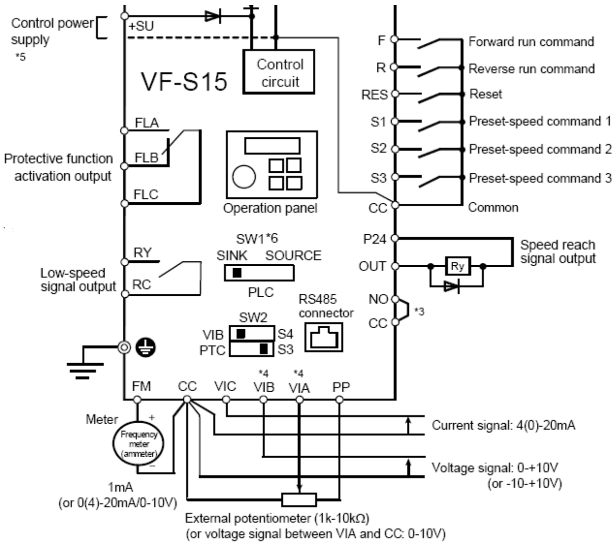

Figure 4: Connection diagram on control circuit terminals

At the control circuit terminal there is a control circuit connected to the power circuit, where the power circuit functions as the power supply and receiver for the output of the control circuit. This terminal also has a terminal for supplying external power as a backup for the control circuit power supply. For input logic terminals on this inverter, there are several ports that also support for input using an external potentiometer.

3. Result and Analysis

3.1 Hardware Testing

Hardware testing includes testing the power supply, battery usage consumption. Power supply testing is done by measuring the voltage and current flowing. The duty cycle test is done by measuring the PWM output from the inverter.

3.1.1 Single Phase Power Supply Test

Table 1: Single-phase AC voltage source testing

Voltage (V)	Current (A)
229,8	0,93
230	0,93
230,1	0,92

In Table 1.The voltage output at the power inverter output has an average voltage value of 229.5 V with an average current value of 0.925 A. This value has fulfilled the 1-phase power supply where the voltage value limit is close to 230 V.

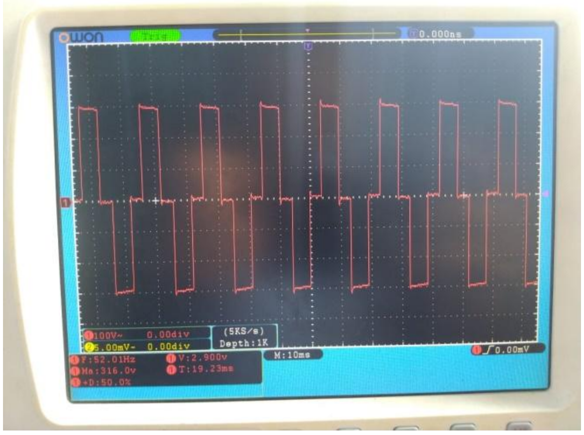

Figure 5: Single phase DC to AC inverter output waveform

In Figure 5 it can be seen that the form of the inverter output voltage is not pure sine wave because the power inverter used is a MSW (modified sine wave) power inverter.

3.1.2 Three Phase Power Supply Test

The voltage imbalance value can be calculated to estimate the unbalance value of the three-phase voltage source that can be tolerated or not. The voltage unbalance value can be calculated based on the following equation:

$$\text{Unbalancing Voltage} = \frac{Maximal\ \ Deviation\ \ from\ Average}{Average} \quad (1)$$

Table 2: Calculation of line to line voltage deviation

Parameter	Value	Deviation Average
Voltage R – S	386,25 V	1,45 V
Voltage S – T	384,7 V	0,1 V
Voltage T – R	383,5 V	1,3 V
Maximal	**386,25 V**	**1,45 V**
Average	**384,8 V**	**0,95 V**

From the calculation data in table 2, it can be seen that the three-phase voltage average value is 384.8 V and the maximum deviation value of the three-phase voltage is 1.45 V. Based on equation (1), the three-phase line to line voltage imbalance is 0.0037 or 0.39%.

Based on the NEMA MG-1-1998 standard regarding electric machines, the three-phase voltage used by the electric engine voltage source is only allowed to have an imbalance of 1%. This shows that the three-phase line to line voltage and the line to neutral voltage that have been measured can be used for the voltage source for three-phase induction motors.

3.1.3 Induction Motor Load Power Test

The measurement of the motor power consumption is carried out to see how much power is used when the motor is subjected to different frequency values. In collecting motor power load data, voltage and current measurements as well as the cosphi value on the motor load side are carried out. The specification of the induction motor used is a 2.2 kW three-phase induction motor.

In testing the value of the fixed variable used is frequency. The value of motor power is obtained from equation 2.

$$P = V.I.Cos\varphi \quad (2)$$

Table 3: Accumulator Power Consumption Measurement

Frequency (Hz)	Voltage (V)	Current (A)	Cos Phi	Power (W)
5	108,08	5,75	0,417	568,01
10	131,63	5,5	0,376	673,3
15	167,9	5,49	0,385	854,5
20	204,71	5,39	0,318	1048,2
25	233,39	5,43	0,292	1212,81
30	265,14	5,44	0,312	1373,12
35	297,9	5,31	0,345	1488,5
40	327,36	5,32	0,277	1673
45	360,08	5,28	0,24	1844,18
50	389,7	5,34	0,305	1976,95

In the test, 10 different frequency variables were carried out, from the test data obtained data including voltage, current, cosphi and power on the motor.

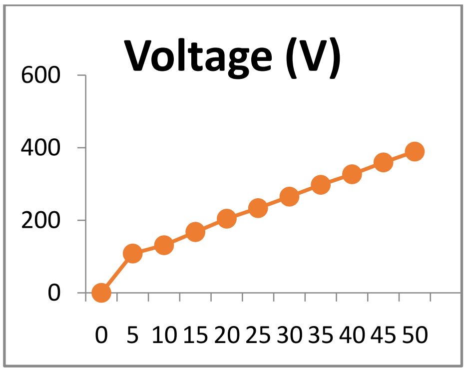

Figure 6: Graph of motor voltage change with frequency

From Figure 6, when the frequency is 5 Hz the voltage value on the motor is measured at 108.08 V. When the frequency value is 25 Hz the measured voltage value is 233.39 V. When the maximum frequency is 50 Hz the voltage value is 389.7 V. From the graph it can be seen that the voltage value increases with increasing frequency value imposed on the induction motor. This value is in accordance with the three-phase voltage standard where, when the maximum frequency the voltage value approaches the value 380 V.

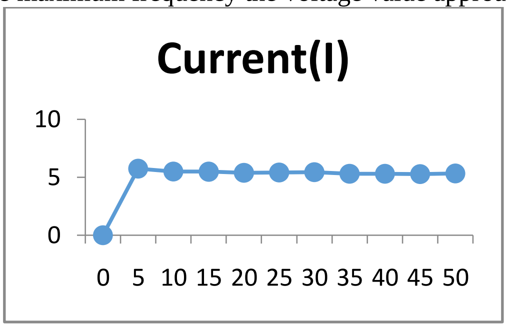

Figure 7: Graph of change in motor current with frequency

When the 5 Hz frequency of the current measured on the motor is 5.75 A, the frequency is 25 Hz, the current is 5.43 A, and when the frequency is 50 Hz the current value is 5.34 A. From Figure 7, the current value is almost constant where at each increase in the frequency range the value of the current is at a value of 5. This shows the frequency has an effect on the value of the voltage but has no effect on the current.

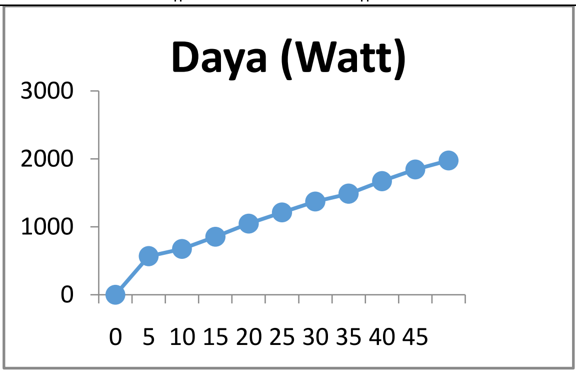

Figure 8: Graph of the change in motor power with respect to frequency

When the frequency of 5 Hz, the power on the motor is 568.01 Watts, the frequency is 25 Hz, the power on the motor is 1212.8 Watts, while when the maximum frequency is 50 Hz the value of the motor power is 1976 Watts. From Figure 8 it can be seen that the value of the increase in frequency is directly proportional to the increase in power. The motor power value when the maximum frequency state has also approached the motor rating value, where the motor rating value is 2200 Watts.

3.2 Software Testing

3.2.1 Speed Sensor Testing

The speed sensor test is carried out in a loadless state with the same frequency parameters. The sensor reading test is done by comparing the sensor reading value with the reading on the tachometer.

Table 4: Speed Sensor Testing

Frequency (F)	Sensor (m/s)	Tachometer (m/s)
0	0	0
5	2,38	2,5
10	4,75	4,9
15	7,15	7,45
20	9,5	9,87
25	11,9	12,40
30	14,49	14,72
35	16,87	17,12
40	19,16	19,61
45	21,34	21,61
50	24,05	24,56

Tests are carried out using 10 different frequency scales. On the 5 Hz frequency setting, the sensor readings are 2.38 m / s, while on the tachometer it is 2.5 m / s. When the frequency is 30 Hz, the speed reading on the sensor is 14.49 m / s, while the tachometer reads 15.4 m / s. From the data that has been obtained, it is found that the sensor and tachometer readings have an average error value of 0.315.

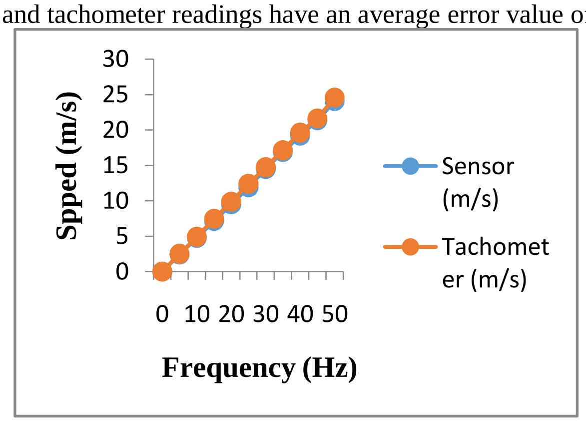

Figure 9: Hall effect sensor test chart

From Figure 9, it can be seen that the sensor and tachometer reading graphs have a slight difference value, this is evidenced by the average error value of 0.315. This is because the sensor readings use a magnet, where the surface area of the magnet also affects the value of the distance reading.

3.2.2 Testing the PWM Duty Cycle inverter

Testing is done by reading the PWM signal that comes out of the inverter through an oscilloscope and the response of the motor speed using a sensor. Testing the pwm signal from the inverter is done by using an oscilloscope on the pwm output pin of the inverter. Duty cycle and pulse width were analyzed against the tested variations. Testing the PWM output signal is done by measuring the positive pulse width or condition when the logic is high through an oscilloscope. Testing is done by providing input variations based on frequency values. The control variations given are with frequency values of 0.5, 10, 15, 20, 25, 30, 35, 40, 45, 50. The frequency value 0 is the minimum value and the frequency value 50 is the maximum value of the PWM used.

Table 5: Duty Cycle Testing

PWM (0-50)	*Duty Cycle* (%)
0	0
5	10
10	20
15	30
20	40
25	50
30	60
35	70
40	80
45	90
50	100

Based on the measurement data in table 5, it can be seen that the duty cycle of the inverter pwm output signal changes linearly to changes in the pwm input signal.

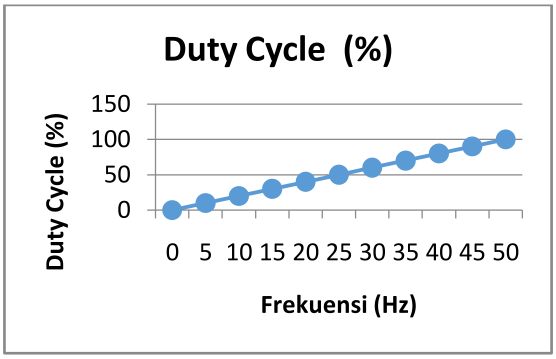

Figure 10: Duty Cycle Testing

3.3 Testing of Frequency Changes Against Motor Rotation Speed When Loaded and Unloaded

This test aims to determine changes in the speed of the electric motor used as an electric car propulsion. Frequency regulation uses a TOSVERT VFS-15 inverter and a 3-phase induction motor as the main drive with a power of 2.2 KW. Electric motor speed test data is carried out by providing variations when the car is not loaded and when the car is loaded (chassis weight ± 60 Kg) by one driver with a mass of 60 Kg.

Table 6: Effect of frequency changes on the rotational speed of loaded and unloaded motors

Frequency (Hz)	Speed Unloaded (Km/Jam)	Speed Loaded (Km/Jam)
5	8,56	7,45
10	17,1	16,56
15	25,74	24,8
20	34,2	29,92
25	42,84	-

30	52,164	-
35	60,732	-
40	68,976	-
45	76,824	-
50	86,58	-

From the data table 6, it is obtained when the frequency of 5 Hz, the speed of the car when without load is 8.56 Km / hour, while for the value of the speed when it is loaded, the measured speed is 7.45 Km / hour. When the frequency is 10 Hz, the measured speed of the car at no load is 17.1 km / hour, when the car is loaded, the measured speed is 16.56 km / hour. When the frequency is 20 Hz, the rated car speed is 34.2 Km / hour, when the car is loaded, the car speed is 29.92 Km / hour, a comparison chart can be made which is shown in Figure 11.

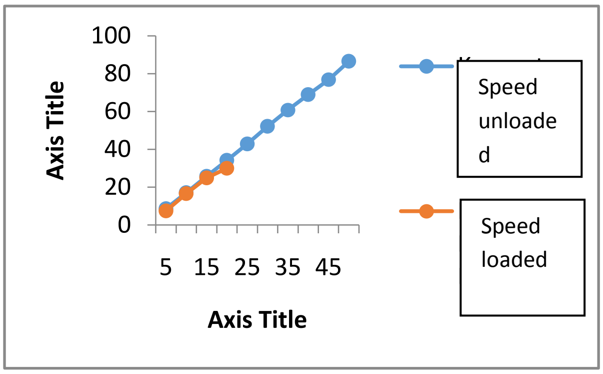

Figure 11: Graph of the effect of frequency changes on the rotational speed of loaded and unloaded motors

From Figure 11, the graph of the speed value between the car when it is loaded and the car is not loaded has a slight difference in value, this can be seen where the curve when 5 Hz, 10 Hz, and 15 Hz shows a graph that coincides with these two parameters. And when in a frequency state of 50 Hz, the speed of the car when it is not loaded is measured at 86.58 km / hour. Measuring in a load condition when the frequency is above 25 Hz is not done because to increase the frequency this value requires time and a long track with a flat road surface.

4. Conclusion

Based on the design, testing, and analysis that has been done, it can be concluded that the three-phase power supply test has a voltage imbalance value of 0.39%. Electric cars with three-phase induction motor drives use VFD (variable frequency device) control media to drive the axle was created successfully. This can be seen from the test results which show that the three-phase induction motor has succeeded in moving the car with a driver load of 60 Kg.

The change in the 3-phase frequency is directly proportional to the motor speed and voltage, the greater the input frequency value, the greater the motor rotation speed value and the greater the voltage value in each phase.

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