Analysis of Induction Motor Based on Field Oriented Control with Modulation Techniques Carrier Based Pulse Width Modulation (CBPWM)

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ABSTRACT

Induction motors have the advantage of simple construction and lower prices. Induction motors have a weakness, namely that they are still coupling, where the interdependence of torque and flux at low speeds regulates the speed more complicated and cannot maintain a constant speed when there is a change in load. To keep the speed of the induction motor can be controlled properly, a method is needed, namely an induction motor using CBPWM with Vector Control. CBPWM can affect the speed of the induction motor, when the Modulation Index is 0.1 the motor speed is 75.03 Rpm and when the Modulation Index 1 the motor speed has an increase of 750 Rpm. From a series of simulations by setting the Modulation Index, as in m=1 it has a speed of 750 Rpm, Maximum Torque 12.1 Nm, Rise Time 0.28s, Settling Time 0.45s, Peak Time 0.93s, and Overshoot 0.01% . Then, the lowest THDi was found at the Modulation Index 1.0 at 1.21% and the lowest THDv was at the Modulation Index 1.1 at 64.91%.

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1. INTRODUCTION

Induction motor is one type of AC electric motor (Alternating Current) which is widely used in everyday life. Induction motors that are commonly used are single-phase induction motors and 3-phase induction motors. The single-phase induction motor is operated on a single-phase power system, while the 3-phase motor is operated on a three-phase voltage. Single-phase induction motors are widely used for household appliances such as fans, refrigerators, and so on because single-phase induction motors have low output power. Meanwhile, the 3-phase induction motor has a higher power. Operation of induction motors, such as elevators, escalators, and large building utility equipment such as pumps, and other industrial equipment.

Induction motors have advantages in their simple construction and relatively cheaper prices in terms of maintenance costs. This motor is very compact in shape, in addition to its advantages, the induction motor has the disadvantage that it is still coupling, where there is an interdependence between torque and flux and at low speeds regulating the speed is more complicated and the motor is not able to maintain a constant speed when there is a change in load. If the load changes, the speed of the induction motor will decrease[1,3].
Thus, to maintain the speed of the induction motor can be controlled properly, a method is needed, namely an induction motor using Carrier-Based PWM with Field Oriented Control techniques. This method is one of the controlled methods in the induction motor system. This method can change the coupling system into a decoupled system in an induction motor. Carrier based method is a method that uses a carrier signal to provide a trigger signal through signal regulation

In this final project, the writer will analyse the induction motor using Carrier-Based Pulse Width Modulation technique. By using the Carrier Based Pulse Width Modulation (CBPWM) modulation technique, it is expected to be able to control the speed of the induction motor, using MATLAB software.

2. MOTOR INDUCTION

An electric motor is used to convert electrical energy into mechanical energy in the form of rotary power. An electric motor consists of two very important parts, namely the stator or stationary part and the rotor or rotating part. In an AC motor, the rotor coil does not receive electrical energy directly, but by induction as happens in the transformer coil energy. Therefore, AC motors are known as induction motors. Judging from its simplicity, strong and sturdy construction and good working characteristics, three-phase induction motors are suitable and most widely used in industry [2,3].

3. INVERTER

Inverter is a power electronic circuit that is used to convert or convert direct voltage to alternating voltage. Based on the number of phases, inverters are divided into single-phase and multi-phase inverters, one of which is the three-phase inverter, which so far is a type of inverter used to interconnect the output to the grid of the electric power system. The use of this type is chosen based on the place of application [4].

In general, three-phase inverters work with the principle of switched mode whose basic circuit is shown in Figure 2.15. The switches in the figure work in such a way that the output voltage forms (A, B, & C) and forms a three-phase voltage.

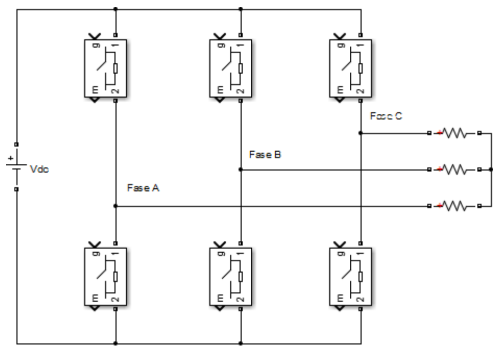


Fig 1. Inverter 3 Phase [5]

4. FIELD ORIENTED CONTROL

Field Oriented Control is a method of controlling the field on an AC motor, where the coupling system is converted to a decoupled system. With this system, the gain current and the motor load current can be controlled separately. Thus, torque and flux can also be regulated separately, as is the case with DC motors [3]. In Figure 2 the induction motor modeling is presented in the d-q model (reference rotating frame). In the control section the iqs * and ids values are set to set the actual input iqs and ids on the induction motor. Between the control section and the induction motor, in this case the desired current value (ia*,ib*,ic*) is converted into the induction motor input (ia,ib,ic) using an inverter. In the process of changing the frame, namely from -β coordinates to d-q and vice versa, cos and sin components are used. This component is called the unit vector.[5,7]

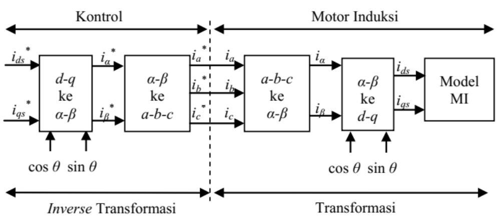


Fig 2. The principle of Field Oriented Control in an induction motor[11]

5. Carrier-Based PWM

The principle of Carrier-based PWM is that pulse generation is obtained by comparing a reference sinusoidal wave (Vref) with a triangular wave or high-frequency triangular wave. The triangular wave is also called the carrier wave (Vc). The pulse of the Carrier-based PWM method is similar to the sine PWM by using the simple logic in equation (2.6) that if the reference sine wave (Vref) is greater than the carrier wave (Vc) then the pulse is 1 (high) and vice versa if the reference sine wave (Vc) is smaller then the pulse is 0 (low). It is called Carrier-based PWM because the dominant carrier wave becomes the modulating wave because the fundamental wave is added up with all the resulting harmonic waves. [8,9]. The carrier wave usually has a frequency at least 20 times faster than the frequency sine wave, so the carrier wave can shift the low harmonic wave quite far from the basic component of the inverter output voltage.

$$
\begin{aligned}
V_{ref} > V_C \qquad & M_X = 1(\text{High}) \\
V_{ref} < V_C \qquad & M_X = 0(\text{Low})
\end{aligned} \tag{1}
$$

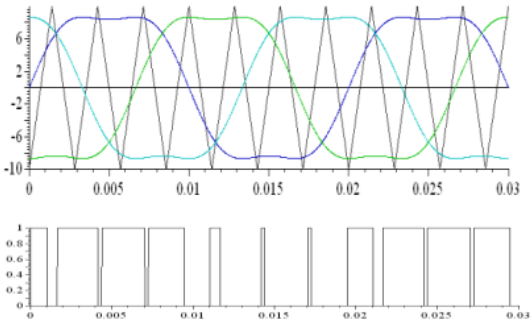


Fig 3. Trigger Signal On Phase A of CBPWM [9]

6. The Harmonic

Harmonic distortion is caused by nonlinear equipment in an electric power system. An equipment is categorized as non-linear if the equipment has an output whose value is not proportional to the applied voltage.

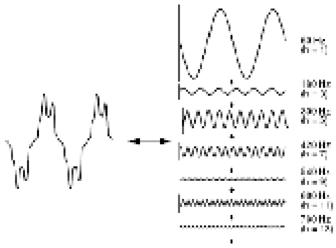


Fig 4. Distortion Wave [10]

Figure 4 shows that each periodic, distorted waveform is the sum of several sinusoidal waves with different frequency variations. The sinusoidal waves that have different frequencies are the product of an integer multiple of the fundamental frequency. The sum of these sinusoidal waves is known as the Fourier series, where Forier is the name of the great mathematician who succeeded in finding a concept that could explain the distorted waves.

The Total Harmonic Distortion (THD) value of a wave can be calculated by the formula [10]:

$$THD = \frac{\sqrt{\sum_{h=2}^{h_{max}} M_h^2}}{M_1} \tag{2}$$

Where Mh is the rms value of the harmonic component h of the quantity M . The quantity M can be in the form of a voltage V or a current I, so that the THDv value is the total harmonic distortion of the voltage and the THDI is the total harmonic distortion of the electric current, where[10]:

$$THD_V = \frac{\sqrt{\sum_{h=2}^{h_{max}} V_h^2}}{V_1} \tag{3}$$

$$THD_I = \frac{\sqrt{\sum_{h=2}^{h_{max}} I_h^2}}{I_1} \tag{4}$$

The rms value of the total waveform is not the sum of each harmonic component, but the square root of the sum of its squares. The relationship between THD and the rms value of the wave is[10]:

$$rms = \sqrt{\sum_{h=1}^{h_{max}} M_h^2} = M_1 + \sqrt{1 + THD^2} \quad (5)$$

Voltage harmonics are always used as a guide for the basic value of the instantaneous waveform. Since the voltage has a small percentage difference, where the voltage THD is an approximation of the actual number. This does not apply to electric current, because a current that has a small value can produce a high THD, so it cannot be used to describe the state of a system[10].

7. METHOD

In this final project, modeling of an induction motor with vector control is carried out, modeling a CBPWM inverter on Simulink MATLAB r2018a. After that do an analysis of the induction motor.

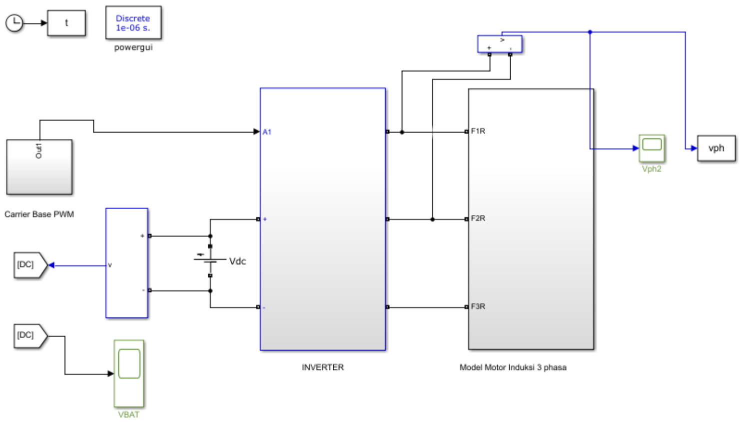


Fig. 5 Induction motor system design with CBPWM modulation technique

Table 1. Induction Motor Parameters[1]

No.	Parameter	Nilai	Satuan
1	Tegangan Motor (V)	380	Volt
2	Frekuensi (f)	50	Hz
3	Jumlah Kutub (P)	2	Pasang
4	Tahanan Stator (Rs)	10	Ohm
5	Tahanan Rotor (Rr)	6.3	Ohm
6	Induktansi Stator (Ls)	0.004	Henry
7	Induktansi Rotor (Lr)	0.004	Henry
8	Induktansi Mutual (Lm)	0.42	Henry
9	Momen Inersia (J)	0.01	N-m
10	Tenaga Motor (P)	5	HP
11	Arus (A)	1.2	Ampere
12	Rpm	1500	rpm

8. RESULTS AND DISCUSSION

In this research, a system simulation is carried out, where there is input data used, namely the Modulation Index data from 0.1-1.15 and the load torque is given to the induction motor of 2 Nm at t=0.5 s and t=0.7 s. The following can be seen the data from the simulation results

Table 2. Data of Simulation Results of No Load System

Indeks Modulasi	Rise Time (s)	Settling Time (s)	Peak Time (s)	Overshoot (%)	Kecepatan (Rpm)
0,1	0,27704	0,45033	0,929749	0,0657	75,03
0,15	0,25154	0,37507	0,671751	0,1581	112,5
0,2	0,24593	0,37637	0,583004	0,0315	150
0,25	0,25392	0,3644	0,575004	0,0576	187,5
0,3	0,25827	0,37196	0,927003	0,014	225
0,35	0,26999	0,37759	0,799254	0,0143	262,5
0,4	0,27979	0,38511	0,487251	0,0039	300
0,45	0,29261	0,39818	0,748002	0,0053	337,5
0,5	0,30317	0,41178	0,836504	0,0037	375
0,55	0,30655	0,42724	0,724253	0,0183	412,5
0,6	0,32371	0,44616	0,916504	0,00025942	450
0,65	0,34184	0,46415	0,735504	0,0086	487,5
0,7	0,36253	0,48622	0,952753	0,0045	525
0,75	0,37393	0,5081	0,980003	0,0068	562,5
0,8	0,39478	0,53225	0,926253	0,00030436	600
0,85	0,42023	0,55918	0,778255	0,0066	637,5
0,9	0,43668	0,58615	0,889753	0,007	675
0,95	0,46354	0,61593	0,843254	0,0039	712,5
1	0,48731	0,64608	0,990502	0,0061	750
1,05	0,51362	0,67898	0,969003	0,0117	787,5
1,1	0,53845	0,71274	0,952758	0,0014	825
.1,15	0,56975	0,74813	0,987251	0,0022	862,5

Based on **Fig. 6**, it can be seen that the Modulation Index affects the response of the induction motor speed system so that the overshoot obtained is lower, when the Modulation Index is greater, the Overshoot is also smaller so that the motor is faster in achieving stability.

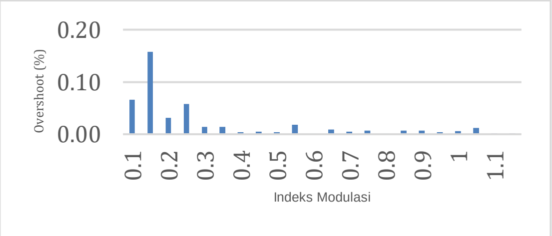


Fig. 6 Relationship of Modulation Index to Overshoot

Based on **Fig. 7**, it can be seen that there are values of Rise Time, Settling Time, and Peak Time that affect the Modulation Index from 0.1 to 1.15 where the greater the Modulation Index, the longer the Rise Time, the fluctuating Settling Time decreases from the Modulation Index 0, 1-0.3 then increased from 0.3-1.15 and the Peak Time value fluctuated.

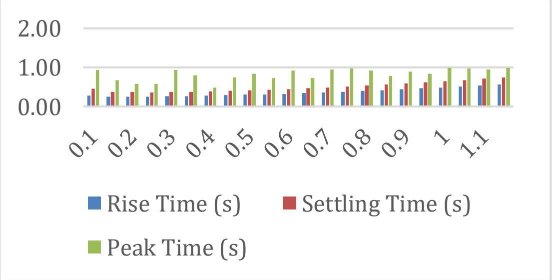
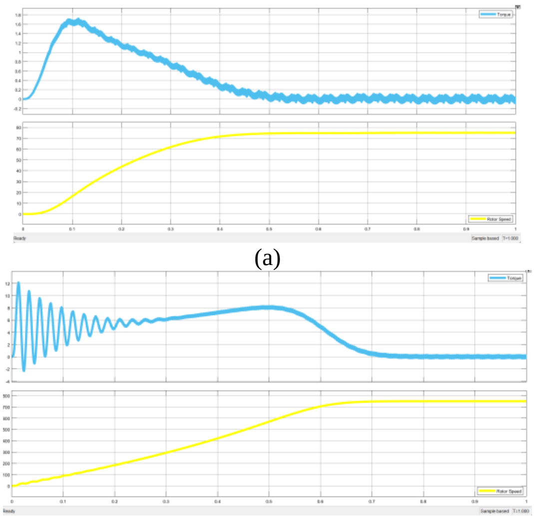


Fig. 7 Relationship of Rise Time, Settling Time, and Peak Time to Modulation Index

Based on Figure 9 it can be seen that the Modulation Index 0.1 with a speed of 75.03 Rpm, the highest torque is 1.7 Nm, Rise Time (up time) 0.28 s, Settling Time 0.45 s, Peak Time (peak time)) 0.93 s, and Overshoot 0.07% later. (b) it can be seen that in Modulation Index 1 with a speed of 750 Rpm, the highest torque is 12.1 Nm, Rise Time is 0.49 s, Settling Time is 0.65 s, Peak Time is 0.99 s, and 0.01% Overshoot. It can be concluded that M=0.1 and M=1.0 experienced an increase in performance.



(a) (b)

Fig. 8 (a) Motor Speed and Torque at 0.1 Modulation Index (b) Motor Speed and Torque at 1 . Modulation Index

Table 3. Data of Simulation Results of Load System

Indeks Modulasi	Rise Time (s)	Settling Time (s)	Overshoot (%)	Peak Time (s)	Kecepatan Rotor (Rpm)
0,1	0,29452	0,95968	30,9782	0,627993	76,9
0,15	0,25419	0,85215	17,9688	0,605007	113,1
0,2	0,24346	0,72977	13,3661	0,590502	149,3
0,25	0,25316	0,7327	9,7742	0,584257	187,2
0,3	0,25824	0,7321	7,5531	0,581255	225
0,35	0,2701	0,7296	6,2233	0,580005	262,6
0,4	0,27983	0,72664	5,3052	0,579252	300
0,45	0,29216	0,72428	4,6327	0,581253	337,5
0,5	0,30318	0,72194	4,1264	0,583253	375
0,55	0,30655	0,72	3,7466	0,585753	412,5
0,6	0,32371	0,71773	3,4316	0,596504	450
0,65	0,34184	0,71557	3,1761	0,611504	487,5
0,7	0,36253	0,71351	2,9517	0,625004	525
0,75	0,37393	0,71154	2,7686	0,659254	562,5
0,8	0,39478	0,70949	2,5993	0,651253	600
0,85	0,42023	0,70773	2,4637	0,682252	637,5
0,9	0,43311	0,70584	2,3337	0,689753	675
0,95	0,45381	0,70387	2,2017	0,700001	712,5
1	0,47209	0,70093	2,0437	0,700001	750
1,05	0,49249	0,63293	1,7103	0,700001	787,5
1,1	0,51114	0,66102	0,871	0,700001	825
1,15	0,53564	0,69009	0,0026	0,957757	862,5

Based on Fig. 9, it can be seen that the Modulation Index affects the response of the induction motor speed system so that the overshoot obtained is lower, with a Modulation Index of 1.15 overshoot of 0.001% so that the motor is faster in achieving stability.

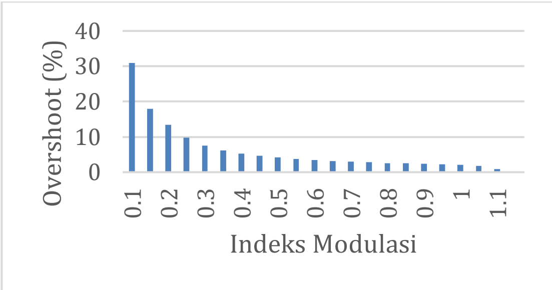


Fig. 9 Relationship of Modulation Index to Overshoot

Based on Fig. 10, it can be seen that there are values of Rise Time, Settling Time, and Peak Time that affect the Modulation Index from 0.1 to 1.15 where the greater the Modulation Index, the longer the Rise Time, the Settling Time decreases and the Peak Time value increases.

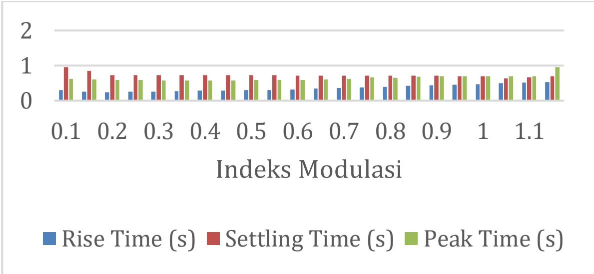
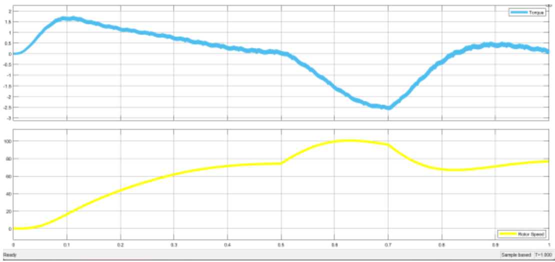
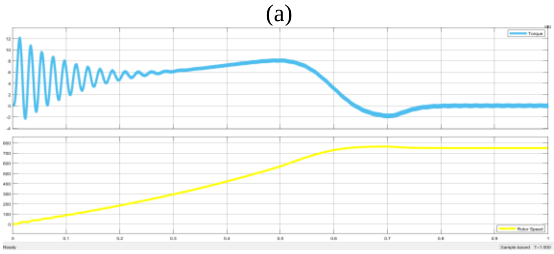


Fig. 10 Relationship of Rise Time, Settling Time, and Peak Time to Modulation Index

Based on Fig. 11, it can be seen that the Modulation Index 0.1 with a speed of 76.9 Rpm, the highest torque is 1.7 Nm, the Rise Time is 0.29 s, the Settling Time is 0.96 s, the Peak Time is) 0.63 s, and Overshoot 30.98% later. (b) it can be seen that at Modulation Index 1 with a speed of 750 Rpm, the highest torque is 12.1 Nm, Rise Time is 0.47 s, Settling Time is 0.70 s, Peak Time is 0.70 s, and 2.04% Overshoot. It can be concluded that M=0.1 and M=1.0 experienced an increase in performance.



(a)



(b)

Fig. 11 (a) Motor Speed and Torque at 0.1 Modulation Index (b) Motor Speed and Torque at 1 . Modulation Index

Table 4. THDi and THDv Simulation Result Data

Indeks Modulasi	THDi (%)	THDv (%)
0,1	127,05	6096,4
0,15	122,8	958,83
0,2	119,8	3004,93
0,25	118,83	751,69
0,3	76,57	788,22
0,35	113,42	1133,89
0,4	83,96	784,42
0,45	103,76	208,17
0,5	140,91	253,29
0,55	66,31	1115,68
0,6	86,48	617,13
0,65	43,48	260,38
0,7	69,45	254
0,75	51,73	154,51
0,8	38,46	128,06
0,85	41,38	107,75
0,9	15,29	86,78
0,95	15,07	77,83
1	1,21	68,53
1,05	13,85	66,71
1,1	38,19	64,91
1,15	38,54	94,52

Based on Fig. 12, it can be seen that the Modulation Index has an effect on THDi and THDv, when the Modulation Index is greater, THDi and THDv decrease. The THDi which has the lowest value is found in the Modulation Index 1.0 at 1.21% while the THDv which has the lowest value is at the Modulation Index 1.1 at 64.91%.

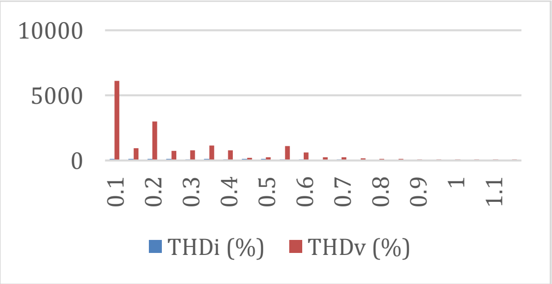


Fig. 12 Relationship of THDi and THDv to Modulation Index

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9. CONCLUSION

The CBPWM modulation technique can affect the speed of the induction motor, when the Modulation Index is 0.1 the motor speed is 75.03 Rpm and when the Modulation Index 1 motor speed has an increase of 750 Rpm, this means that this technique affects the motor speed.

From a series of simulations made by setting the value of the Modulation Index, as in M=1 has a speed of 750 Rpm, Maximum Torque 12.17 Nm, Rise Time (rise time) 0.28 s, Settling Time 0.45 s, Peak Time (peak time) 0.93 s, and Overshoot 0.01%. with the increase in the given Modulation Index, the better the performance which is indicated by the higher speed of the motor, both loaded and unloaded.

From a series of simulations made by adjusting the Modulation Index, the lowest THDi is found at the Modulation Index 1.0 at 1.21% and the lowest THDv is at the Modulation Index 1.1 at 64.91%.

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