MODELING AND ANALYSIS OF AC-AC SOFT STARTER FOR INDUCTION MOTOR BASED ON THYRISTOR AND IGBT

Anisa Harumwidiah[1], Adi Kurniawan[2]

[1]Politeknik 17 Agustus 1945 Surabaya
[2]Institut Teknologi Sepuluh Nopember Surabaya
*Corresspondence : aharwid@gmail.com

Abstract

Motor Starting on large capacity induction motor using direct on-line starting (DOL) method may cause a problem for system. It is due to motor start-up current that can be up to eight times of the nominal current. Soft starter is an induction motor starting method based on power electronic that can significantly decrease motor starting current, resulting in reduced fuel consumption. In this research, a comparison between DOL starting method and two soft starter methods based on thyristor and Insulated Gate Bipolar Transistor (IGBT) is performed. The results show that thyristor based soft starter method with firing angle 90° can reduce input voltage from 220 V to 165 V so that the maximum starting current down from 633 A to 265 A. In the same voltage value, IGBT can reduce maximum starting current to only 100 A.

History:

Received: December 11, 2015
Accepted: December 12, 2015
First published online: December 21, 2015

Keywords:

Soft starter
Induction motor starting
Thyristor
IGBT

1. Introduction

Three-phase induction motor is widely used in industrial application due to its low cost, high reliability and easy maintenance. The most common starting method for induction motor is direct on-line (DOL) starting which directly connected induction motor to the electrical grid. The use of DOL starting for large motor may cause problem for the grid because the high starting current of the motor resulting high surge voltage and fluctuation of the torque (Bruce et al, 1984). The high starting current of induction motor may also causing trip on under voltage and over current relay, and thus resulting fail operation. Furthermore, higher starting current also causes higher fuel consumption on the generator, leads to more air pollution. Therefore, a method to reducing starting current is technically, economically and environmentally advantageous.

One of the methods to reduce induction motor starting current is by using special device called auto transformer to lower peak input voltage. However, auto transformer is expensive and has large dimension, so that it is not a favorable solution.

Since the development of power electronics converter, many improvements have been made in electrical motor area. Not only for controlling the speed of the motor (Kurniawan & Harumwidiah, 2015), power electronics converter also offering a new method to reduce the current start of induction motor. The use of power electronics converter is arising and replacing auto transformer method (Eltamaly et al, 2007). The use of power electronics converter for motor starting is called soft starting method. Unlike the auto transformer method, the peak input voltage does not change. However, the RMS input voltage is decrease because of cutting waveform.

The common soft starter method is using two reverse thyristor. However, thyristor has some disadvantages. The use of thyristor soft starter method is causing low harmonics order, resulting great harmonics losses and decrease of energy saving in network. The incurred harmonics not only will affect transient performance of the motor, but also decrease the power factor of the system (Suryoatmojo et al, 2014).

Since the development of self-commutated switches such as IGBT, the use of thyristor in industry is decreasing though thyristor still mainly used as induction motor starting application. In self-commutated switches, the stator voltage can be regulated just by changing the duty cycle and doesn't need synchronization with AC source. The switching frequency operation of IGBT is much higher than system frequency, so that the stator current is almost perfectly sinusoidal (Ahmed et al, 2009). This paper compares the performance of induction motor with the thyristor soft starter method and with the IGBT method. The comparison focus on the RMS starting current and the total harmonics distortion (THD) caused by each method.

2. Methodology

In this research, a computer based simulation has been done to investigate performance of various starting method for three phase induction motor. There are three starting method that been investigated which is Direct on Line (DOL) starter, soft starter with thyristor and soft starter with IGBT. The simulation time is set to 6 seconds in order to wait until the current waveform is reaching steady state.

The data that required and collected from each method are:

a. Motor input voltage and current waveform
b. Root mean square (RMS) voltage and current
c. Maximum starting current
d. Total harmonic distortion (THD) for voltage and current

The detailed information for each starting method is explained below.

DOL Starting Model

The configuration of DOL starting method for induction motor is shown in Figure 1. In this method, each phase of three-phase induction motor is connected to each phase of three-phase voltage source through a switch. The switch may connect or disconnect the motor to the source. The three-phase source is 50 Hz, 380 V RMS interphase. The motor is given 50 Nm load torque. The specification of the induction motor used in this simulation is shown in Table 1.

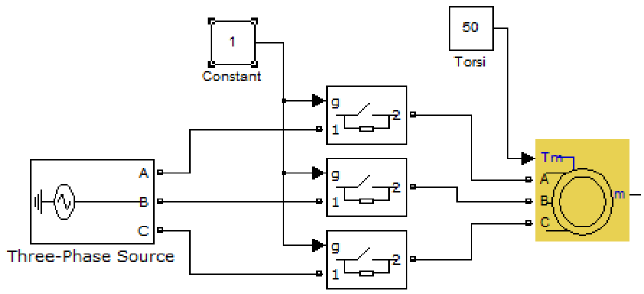


Figure 1. The configuration of DOL starting method for induction motor

Table 1. Parameters of induction motor

Parameter	Value
Power	30 kVA
Voltage (line to line)	380 volt
Frequency	50 Hz
Poles	2

Soft Starter with Tyristor Model

Figure 2 shows the configuration of thyristor based soft starter for induction motor. The circuit is composed of three-phase AC voltage source, three set of thyristor, and an induction motor. Each set of thyristor consist of two thyristor installed reversely. The induction motor is exactly the same with the induction motor that used in DOL starting model.

In steady condition, induction motor is supplied directly by pure sinusoidal voltage. At start, the sinusoidal input voltage is cut by the thyristor so that it is not pure sinusoidal anymore. The cutting value is proportional to the firing angle given. The thyristor will only conduct the voltage and current from the source to the motor after the thyristor is ignited at the firing angle. Therefore, the input voltage of the motor at start is smaller than at steady condition. Thus, the objective of this starting method can be obtained.

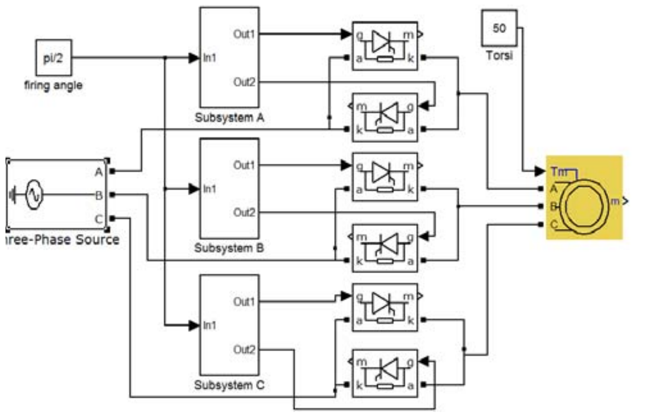


Figure 2. The configuration of soft starter with thyristor for induction motor

The control topology for the each phase of thyristor is shown in Figure 3. The firing angle reference is compared with triangle waveform. If the angle reference value is higher than the triangle, the control circuit will activate the thyristor. On the contrary, if the triangle is higher, the control circuit will not activate the thyristor.

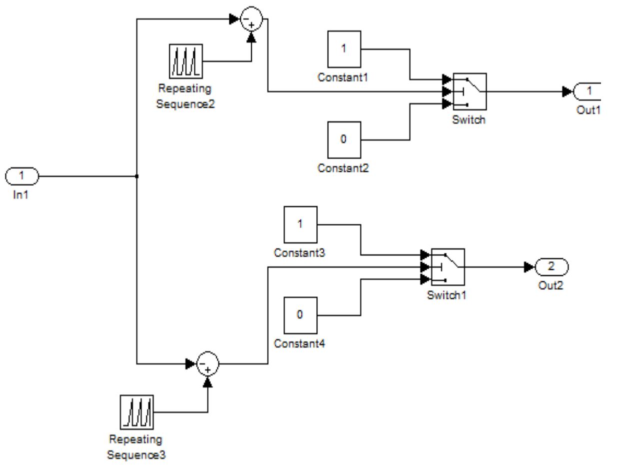


Figure 3. The control topology for one phase of soft starter with thyristor

Soft Starter with IGBT Model

The configuration of IGBT based soft starter method is shown in Figure 4. The configuration is similar with the thyristor based mode, only IGBT is replacing the thyristor.

Similar with thyristor based model, the IGBT also cutting the sinusoidal voltage from the source though with different method. If the thyristor only cut the voltage at the initial phase angle, the IGBT is cutting the sinusoidal wave in all phase angles. The value of the voltage cut depends on the modulation index value given to the control circuit. The smaller the modulation index value is, the more voltage being cut. The smaller motor input voltage at start resulting smaller starting current.

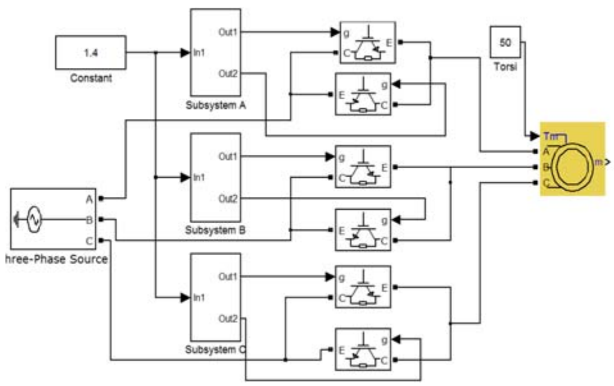


Figure 4. The configuration of soft starter with IGBT for induction motor

Figure 5 shows the control topology for one phase of IGBT. This control method is similar with the thyristor based mode, because it also comparing the reference RMS value with triangle waveform, to control when the IGBT should on and when it should off.

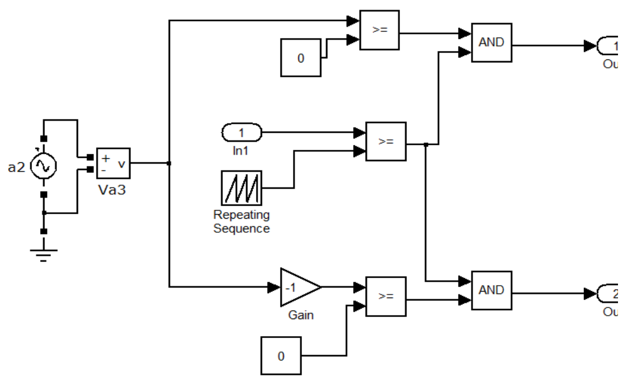


Figure 5. The control topology for one phase of soft starter with IGBT

3. Results & Discussion

The three starting method that modeled above is run at the computer simulation. The results being analyzed are the starting current and the harmonics, especially for thyristor based soft starter and IGBT based soft starter. Theoretically, the DOL starting method may not generate high harmonics value because there is no voltage wave cut.

DOL Starting Simulation Results

DOL starting method is not cutting the input voltage that fed to the motor. Therefore, the motor input voltage with this method is pure sinusoidal. Figure 6 shows the phase input voltage of the induction motor with 220 V RMS value or 311 V peak value.

The motor input current waveform is shown in Figure 7. The amplitude of the current at start is reaching 633 A. By the time, the current amplitude is getting smaller until it reaches the steady state. It takes around 0.5 seconds until the current is steady. The amplitude of steady state current is 36 A or 22.55 A RMS value.

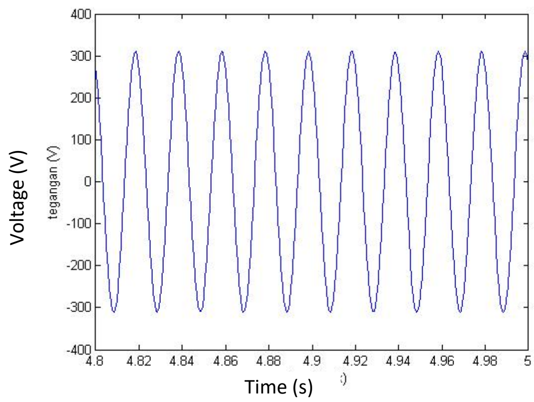


Figure 6. Motor input voltage using DOL starting method

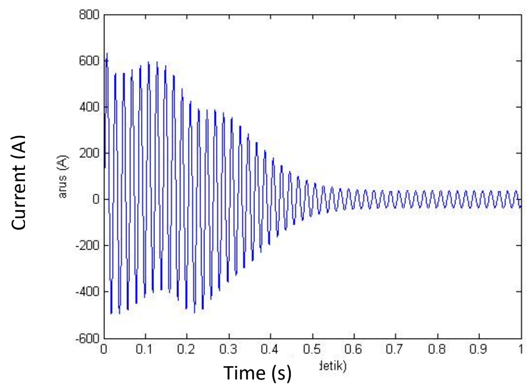


Figure 7. Motor input current using DOL starting method

Soft Starter with Thyristor Results

In this simulation, the thyristor soft starter is used until 4th second. After 4 seconds, the current is already reaches the steady state value, so the soft starter is released and the motor directly connected to the voltage source. Maintaining the soft starter at steady state condition is unwise because of the generated voltage and current harmonics may damage the motor. When the soft starter is used with 90˚ firing angle, the RMS voltage value is 165 V. The motor input voltage waveform with the thyristor based soft starter ignited at 90˚ and released at 4th second is shown in Figure 8.

Figure 9 shows the motor input current. The first 4 seconds shows the motor input current resulting from soft starter application, while the last 4 seconds shows the current after soft starter released. The peak of the starting current with this method is only 265 A, with 36.03 A RMS value. However, compared with DOL start method, this soft starter method needs longer time until the current reaches its steady state. It need about 2.5 second or 5 times longer than DOL method.

The investigation of the effect of thyristor firing angle to the voltage and current is also performed. Table 2 shows the effect of firing angle variation from 60˚ until 100˚. The results show that the bigger the firing angle is, the lower the amplitude of the starting current is, but the higher the total harmonics distortion (THD) of voltage and current is. Therefore it needs a further investigation to determine the optimum firing angle by balancing the starting current and the THD.

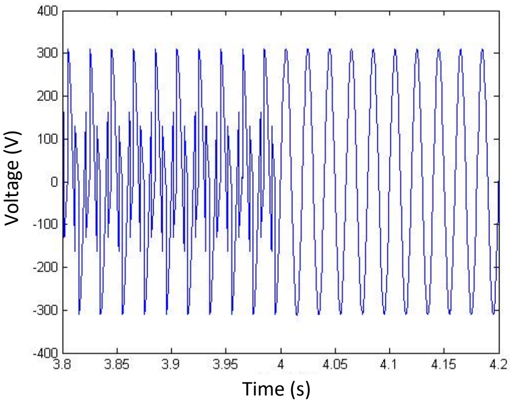


Figure 8. The motor input voltage using soft starter with thyristor

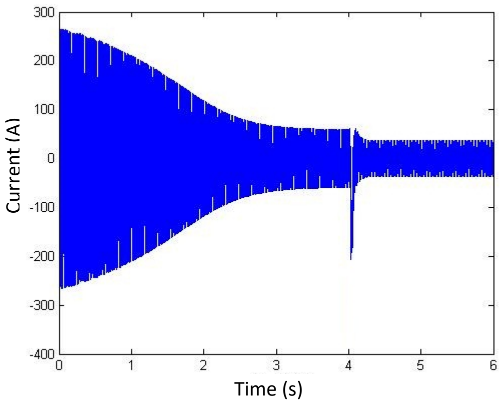


Figure 9. The motor input current using soft starter with thyristor

Table 2. Results of soft starter with thyristor with variation of firing angle

α	Vrms (V)	THD V (%)	Imax (A)	Irms (A)	THD I (%)
60	215,9	4,69	513,5	25,57	8,77
70	206,3	11,22	437	25,89	20,48
80	179,3	37,23	352	27,86	36,15
90	165	98	265	36,03	45,87
100	167,2	199,2	193,6	56,99	39,8

Soft Starter with IGBT Results

The input voltage and current waveform of the motor by using this method is shows in Figure 10 and Figure 11 respectively. The soft starter is released around 4.5th second or until the current reaches the steady state. The RMS voltage value at start is only 164.4 V with 0.57 modulation index. The peak value of the starting current is only 100 A with 33.17 A RMS value. The peak starting current is much lower than in the thyristor based soft starter.

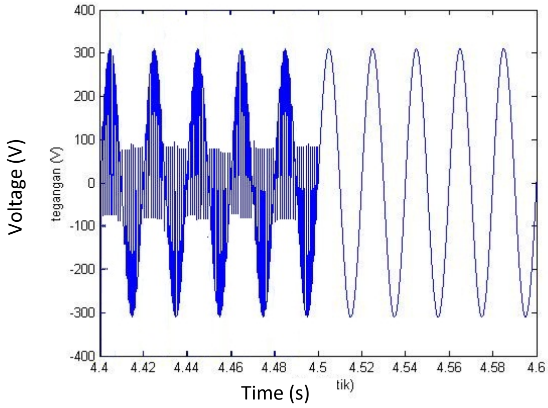


Figure 10. The motor input voltage using soft starter with IGBT

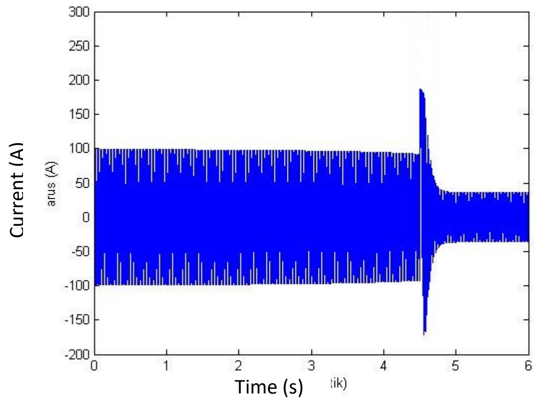


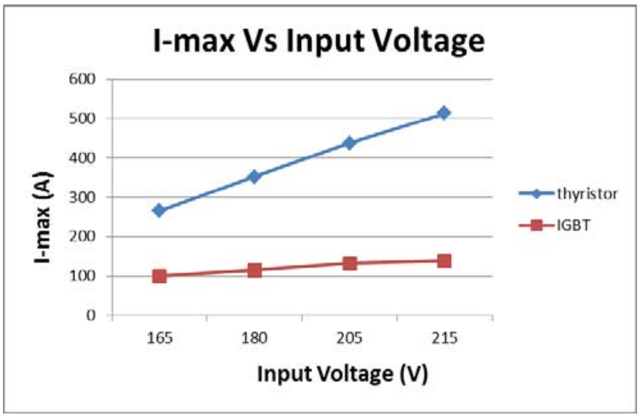
Figure 11. The motor input current using soft starter with IGBT

The effect of the modulation index value to the voltage and current is also investigated and the results are written in Table 3. The results show that higher modulation index resulting higher peak starting current but lower THD of voltage and current.

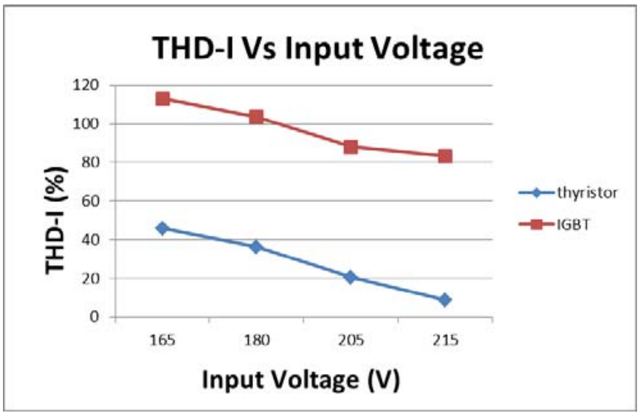
Table 3. Results of soft starter with IGBT with variation of modulation index

m	Vrms (V)	THD V (%)	Imax (A)	Irms (A)	THD I (%)
0,57	164,4	127,4	100	33,17	113
0,63	180,3	118,1	115	34,04	103,6
0,73	205,9	97,22	132	47,58	88,1
0,77	215,4	93,6	138	50,91	83,45

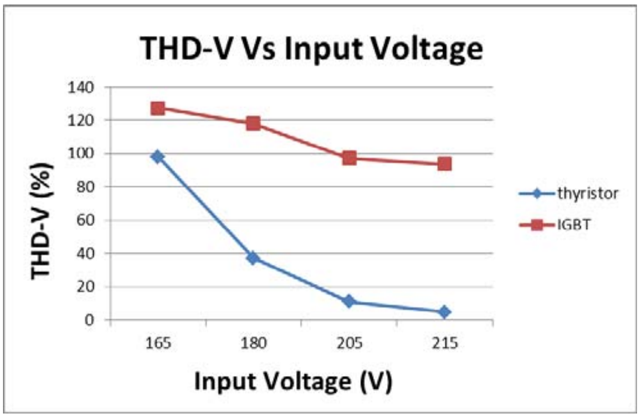
From the simulation results of the two soft starter methods, the comparison graphic of the input voltage to peak currents, and graphics of input voltage to THD can be made and shown in Figure 12. Figure 12(a) shows input voltage to peak current graphics of the two soft starter method. The peak current generated in IGBT based soft starter is smaller than in thyristor based soft starter at the same input voltage. However, Figure 12(b) and Figure 12(c) shows that both of current THD and voltage THD is higher when IGBT soft starter is applied, if compared with thyristor soft starter.



(a)



(b)



(c)

Figure 12. The comparison graphic of soft starter method with thyristor and IGBT (a) input voltage to peak currents (b) input voltage to current THD (c) input voltage to voltage THD

4. Conclusion

1. The investigation results show that the application of soft starter method for induction motor can reduce the starting current compared with DOL start.
2. The advantages of soft starter with IGBT are the smaller starting current and easier control than with thyristor
3. The IGBT soft starter method also has disadvantages because of the higher value of THD compared with the THD in soft starter with thyristor.
4. The optimum modulation index of soft starter with IGBT should be investigated by considering both of starting current and THD.

References

Bruce, F.M., Graefe, R.J., Lutz, A., Panlener, M.D., 1984, *Reduced Voltage Starting Of Squirrel Cage Induction Motors*, IEEE Transactions on Industry Applications, vol. IA-20, no. 1, IEEE, New Jersey

Eltamaly, A.M., Alolah, A.I., Hamouda, R.M., 2007, *Performance Evaluation of Three-phase Induction Motor under Different AC Voltage Strategies*, Proceeding of International Aegean Conference on Electrical Machines and Power Electronics 2007, IEEE, Bodrum

Kurniawan, A., Harumwidiah, A. 2015, *Strategi Kendali Kecepatan Motor Induksi Menggunakan PWM Inverter Berbasis Jaringan Saraf Tiruan*, Jurnal Transmisi, vol.17, no. 2, Jurusan Teknik Elektro Universitas Diponegoro, Semarang

Riyaz, A., Iqbal, A., Moinoddin, S., MoinAhmed, S.K., Abu-Rub, H., 2009, *Comparative Performance Analysis Of Thyristor and IGBT Based Induction Motor Soft Starters*, International Journal of Engineering, Science and Technology, vol. 1, no. 1, Engg Journals Publications, Chennai

Suryoatmojo, H., Kurniawan, A., Pamuji, F.A., Nursalim, S.T., Wijaya, I.G.P.S., Innah, H., 2014, *A Robust Frequency Control Approach in PV-Diesel Hybrid Power System*, IPTEK Journal of Proceedings Series, vol. 1, no. 1, Institut Teknologi Sepuluh Nopember, Surabaya