Educational Starting Board for Three-Phase Squirrel Cage Induction Motor

Ali Kitaneh, Ahmad Jarrad, Samer Alsadi, Arafat Zeidan, Tareq Foqha, Abdulelah AlWahhabi, and Hani Attar

Abstract When an electric load is turned on, it creates an inrush current. During the starting period, an Induction Motor draws a high starting current which can have an impact on electromagnetic torque, speed, and current. There are various ways to start AC induction motors, such as full voltage, reduced voltage through methods like autotransformer or star-Delta, soft starters, or adjustable speed drives. Reduced voltage starting can be helpful in decreasing starting torque and preventing damage to the load. To choose the appropriate starting method for a motor, an analysis of the power system and the starting load is essential to ensure that the motor can deliver the required performance while minimizing cost. In this project, an educational starting board will be designed for the three-phase squirrel cage induction motor in the Electrical Machine Lab at Palestine Technical University (Kadoorie). This board will allow students to learn different general methods of starting three-phase squirrel cage induction motors, such as full voltage (DOL), reduced voltage (Y-Δ, Autotransformer, and Soft Starter), and variable frequency drives (VFD). The highest starting current is the direct conduction current, and the other methods discussed in this project will solve this issue.

Keywords Starting methods of induction motors · Matlab · Electrical machines lab at Palestine Technical University

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1 Introduction

The project focuses on asynchronous motors, which are a type of motor that require a starting method to reduce starting currents, prevent overheating, and provide overload and no-voltage protection. 3-phase induction motors are capable of self-starting due to the rotating magnetic field generated by the stator's 3-phase windings when connected to a 3-phase power supply. However, various starting methods such as Direct On-Line Starter (DOL), Star-Delta Starter, and Soft Starter are used to reduce starting currents and provide protection. Electrical machines are classified into transformers, generators, and motors, with motors divided into two main types: synchronous and asynchronous [1, 2].

In this project, the results will also be compared with each other and the effect of each method on the starting current, torque and motor speed will be noted to know the appropriate motor for each application. A simulation was also carried out using the "MATLAB" Simulink to compare the results with the practical results.

The starting methods are designed in an educational form for students that combines five starting methods to teach students how to start and put them in the electrical machine lab.

According to Ref. [3], the most common starting methods and their recommended applications are discussed. There are several ways to start an induction motor, and the selection of the most suitable method depends on various factors such as power system limitations, equipment cost, and the requirements of the driven equipment. The full voltage method is considered the easiest and least expensive in terms of equipment, but it may result in cost penalties from the utility, or the power system at the location may not be able to handle the necessary energy draw. Reduced voltage methods are effective in reducing the energy draw required during starting but may come at the expense of motor generated torque during starting. As a result, these methods may necessitate the use of a larger motor to generate the torque needed for the load.

In Ref. [4], the authors introduced a starting controller that is synchronized with the stator of the motor at the starting point to decrease the initial inrush of current. The study revealed that the starting torque of the Direct On-Line (DOL) starter is significantly higher than the starting speed of the same induction motor when it is connected to a Star-Delta or Auto-Transformer starter.

Our project objectives can be summarized as follows:

1. Creating an educational starting board for three-phase squirrel cage induction motor for an electrical machine lab at Palestine Technical University-Kadoorie. It contains five methods to start, namely, Direct on line (DOL), Stardelta connection (Y-D connection), Autotransformer, Soft starter, Variable frequency driver (VFD).
2. Application of starting methods using "MATLAB" Simulink.

2 Starting Method of Three-Phase Induction Motors

AC induction motors have a stator and rotor with an air gap between them. Only three-phase AC induction motors generate a rotating magnetic field naturally in the stator, while DC motors and single-phase AC induction motors require other methods to generate this field.

A motor contains two sets of electromagnets. In the case of an AC induction motor, one set of electromagnets is formed in the stator due to the AC supply that is connected to the stator windings. Because of the alternating nature of the supply voltage, an Electromagnetic Force (EMF) is induced in the rotor (similar to how voltage is induced in the transformer secondary) in accordance with Lenz's law. This creates another set of electromagnets, hence the name "induction motor." The interaction between the magnetic fields of these electromagnets generates a twisting force, or torque, causing the motor to rotate in the direction of the resultant torque [5, 6].

Induction Motors have a drawback in the form of high starting current, which can cause harm to the stator windings and lead to fluctuations in grid voltage. When a three-phase, squirrel-cage induction motor is connected to the full line voltage, the initial surge of current briefly reaches extremely high values, up to 400–600% or more of the rated full-load current, as depicted in Fig. 1 [7].

Due to the high starting current of a three-phase squirrel-cage induction motor, the input current to the stator windings will also be high during the starting process. Therefore, starting protection that is rated as high as 300% of the rated full-load current is typically provided for installations of such motors [1, 8].

Excessive inrush currents drawn by induction motors during startup can cause a significant drop in the connected bus voltages. This voltage dip can affect the operation of other motors on the same bus. In fact, during the startup of large motors, the voltage dips can cause some of the motors operating on the same bus to trip. Hence, it is important to use appropriate starting methods to limit the inrush currents during motor startup. There are several methods for starting an induction motor: which are full voltage (DOL), reduced voltage (Y-Δ, Autotransformer and Soft Starter) and

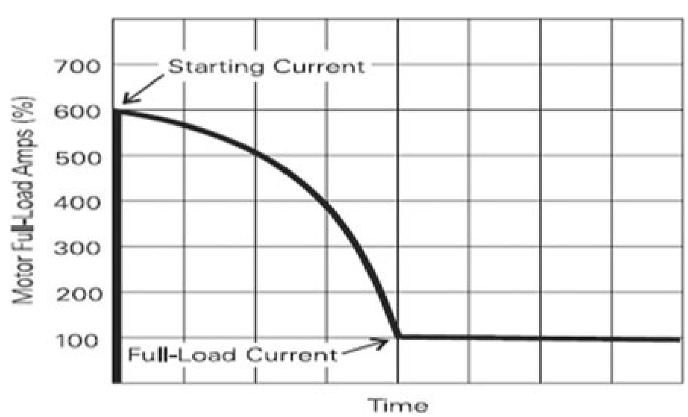

Fig. 1 Starting current of a three phase induction motor

Fig. 2 Connecting the components of the board from the inside

variable frequency drives (VFD), other starting techniques are also used, often with the aim of reducing the inrush currents while maintaining the starting torque.

3 Methodology

The article describes a study conducted on a motor in the university's electrical machinery lab to solve the problem of high starting current. The motor was tested using different starting methods that were assembled and operated using appropriate components. The methodology involved collecting information about the motor, selecting appropriate components, testing each starting method, assembling them in a panel, and comparing the results. The study aimed to identify the most efficient starting method to reduce starting current and its negative effects on the motor and the network. Each method was finally assembled and collected in one panel as shown in Fig. 2. Flowchart in Fig. 3 represents the methodology of this work.

4 Results

The results of the operation of each method of starting an induction motor, which are the starting current, the time of the starting current, the motor rotational speed and torque in different cases will be evaluated and compared for each method.

4.1 DOL Starting Method Results

See Tables 1 and 2.

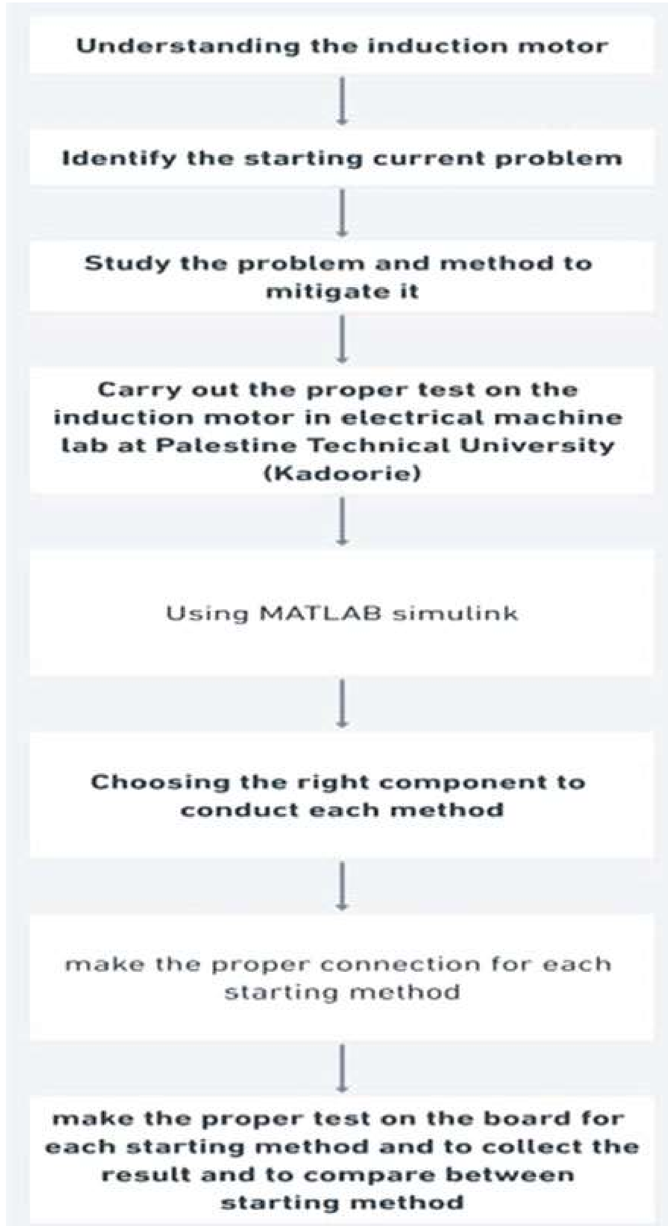

Fig. 3 Methodology of this study

4.2 Y-Δ Starting Method Results

See Table 3.

4.3 Autotransformer Method Results

See Tables 4 and 5.

Table 1 DOL results with Y-connection

At 400 V and time for starting current is 4 ms				
Torque gm/m	I starting Ampere	I motor Ampere	Speed RPM	I starting/I motor
No load	2.75	0.335	2984	8.209
20	3	0.338	2973	8.875
40	3.1	0.345	2957	8.986
60	3.2	0.361	2943	8.864
80	3.4	0.380	2927	8.945
100	3.5	0.401	2905	8.728

Table 2 DOL results with Δ-connection

Direct-on-line results as a Δ-connection at 230 V					
Torque (gm/m)	I starting (Ampere)	I motor (Ampere)	T starting (ms)	Speed (RPM)	I starting/I motor
No load	3.3	0.524	20	2986	6.3
20	6.3	0.532	10	2967	11.84
40	6.6	0.545	4	2948	12.1
60	6.8	0.574	5	2929	11.85
80	7	0.610	4	2905	11.47
100	7.2	0.653	4	2885	11

Table 3 Y-Δ results

Torque (gm/m)	Time (s)	Y starting (A)	Delta starting (Ampere)	Speed RPM	I_{LY} (Ampere)	$I_{L\Delta}$ (Ampere)	IY starting/ ILΔ
0	2.5	2.3	1.6	2990	0.139	0.282	8.16
	5	2.2	1.5	2986	0.134	0.283	7.77
	10	2.2	1.5	2986	0.134	0.283	7.77
50	2.5	2.6	1.7	2938	0.289	0.311	8.36
	5	2.5	1.2	2937	0.288	0.311	8.04
	10	2.45	1	2840	0.290	0.305	8.03
100	2.5	2.6	2.4	2880	0.570	0.383	6.79
	5	2.6	2.3	2885	0.573	0.381	6.82
	10	2.6	2.4	2878	0.570	0.384	6.77

Table 4 Autotransformer starter results as a Y-connection

Y-connection						
T (g.m)	V (volt) (%)		I starting (A)	I motor (mA)	Speed (RPM)	I starting/I motor at full load (400 V)
No load	25	100	0.7	0.144	2794	2.06
	50	200	2.15	0.128	2960	6.34
	75	300	2.75	0.190	2985	8.11
	100	400	3.10	0.339	2987	9.14
50	25	100	0.78	0.741	317	2.26
	50	200	2.22	0.310	2750	6.43
	75	300	3.10	0.260	2905	8.98
	100	400	3.30	0.345	2946	9.56
100	25	100	0.9	0.673	115	2.28
	50	200	4.40	0.54	2506	11.14
	75	300	3.20	0.375	2817	8.10
	100	400	3.6	0.395	2901	9.11

Table 5 Autotransformer starter Results as a Δ-connection

Δ-connection						
T (g.m)	V (volt) (%)		I starting(A)	I motor (mA)	Speed (RPM)	I starting/I motor at full load (400 V)
No load	25	58	2.05	0.225	2812	3.67
	50	115	3.60	0.215	2955	6.44
	75	173	5.00	0.321	2978	8.94
	100	230	5.90	0.559	2987	10.55
50	25	58	2.3	1.12	140	3.90
	50	115	3.8	0.50	2757	6.44
	75	173	5.4	0.433	2905	9.15
	100	230	6.6	0.59	2947	11.19
100	25	58	2.4	1.2	113	3.60
	50	115	4	0.994	2409	6.00
	75	173	5.8	0.650	2810	8.71
	100	230	7	0.666	2898	10.51

4.4 Soft Starter Method Results

See Tables 6, 7, 8, 9, 10, 11, 12 and 13.

Table 6 Soft starter results as a Δ-connection when V_{in} = 40% and rise time = 5s

Δ-connection					
V_{in} = 40%			Rise time = 5 s		Fall time = 0 s
T (g.m)	I st	Speed	V st	I motor	I st/I motor
0	2.7	2983	89	0.524	5.15
50	3.9	2940	89	0.617	6.32
100	4.58	2886	90	0.665	6.89

Table 7 Soft starter results as a Δ-connection when V_{in} = 55% and rise time = 5s

Δ-connection					
V_{in} = 55%			Rise time = 5 s		Fall time = 0 s
T (g.m)	I st	Speed	V st	I motor	I st/I motor
0	3.4	2987	118	0.528	6.44
50	4	2940	116	0.557	7.18
100	4.6	2884	113	0.671	6.86

Table 8 Soft starter results as a Δ-connection when V_{in} = 70% and rise time = 5s

Δ-connection					
V_{in} = 70%			Rise time = 5 s		Fall time = 0 s
T (g.m)	I st	Speed	V st	I motor	I st/I motor
0	4.35	2984	155	0.53	8.21
50	4.6	2946	157	0.552	8.33
100	4.8	2879	152	0.670	7.16

Table 9 Soft starter results as a Δ-connection when V_{in} = 100% and rise time = 2 s

Δ-connection					
T (g.m) = 100			Rise time = 2 s		Fall time = 0 s
V_{in} (%)	I st	Speed	V st	I motor	I st/I motor
40	4.8	2888	93	0.660	7.27
55	4.7	2886	114	0.665	7.07
70	4.5	2884	148	0.662	6.80

Table 10 Soft starter results as a Y-connection when V_{in} = 40% and rise time = 5 s

Y-connection					
V_{in} = 40%			Rise time = 5 s		Fall time = 0 s
T (g.m)	I st	Speed	V st	I motor	I st/I motor
0	2.2	2989	185	0.345	6.38
50	3	2946	180	0.360	8.34
100	3.4	2910	174	0.401	8.48

Table 11 Soft starter results as a Y-connection when V_{in} = 55% and rise time = 5 s

Y-connection					
V_{in} = 55%			Rise time = 5 s		Fall time = 0 s
T (g.m)	I st	Speed	T (g.m)	I st	I st/I motor
0	3.2	2988	225	0.347	9.22
50	3.3	2945	221	0.361	9.14
100	3.5	2906	230	0.403	8.68

Table 12 Soft starter results as a Y-connection when V_{in} = 70% and rise time = 5 s

Y-connection					
V_{in} = 70%			Rise time = 5 s		Fall time = 0 s
T (g.m)	I st	Speed	T (g.m)	I st	I st/I motor
0	3.4	2987	280	0.346	9.83
50	3.8	2945	277	0.362	10.50
100	3.95	2905	273	0.405	9.752

Table 13 Soft starter results as a Y-connection when V_{in} = 100% and rise time = 2 s

Y-connection					
T (g.m) = 100			Rise time = 2 s		Fall time = 0 s
V_{in} (%)	I st	Speed	V st	I motor	I st/I motor
40	3.4	2895	190	0.410	8.29
55	3.5	2902	220	0.410	8.54
70	4	2899	280	0.409	9.781

4.5 Variable Frequency Drive Method Results

See Tables 14, 15 and 16.

Table 14 Variable frequency driver (VFD) results when torque is 0

T = 0 g.m		
L1 current	L1–L2 voltage	Frequency
0.1687	61.39	6
0.1153	111.24	22
0.1138	165.84	28
0.1275	227.49	35
0.1683	309.14	46
0.2200	397.05	50
0.2465	409.77	50
0.2525	413.54	50

Table 15 Variable frequency driver (VFD) results when torque is 50

T = 50 g.m		
L1 current	L1–L2 voltage	Frequency
0.1766	76.00	7
0.3996	173.64	18
0.2948	269.73	29
0.2761	346.35	38
0.2767	387.95	45
0.2919	411.61	49
0.2925	414.32	50
0.2917	415.07	50

Table 16 Variable frequency driver (VFD) results when torque is 100

T = 100 g.m		
L1 current	L1–L2 voltage	Frequency
0.2456	89.73	5
0.5154	152.76	12
0.5168	159.01	17
0.5182	258.86	28
0.3670	406.31	37
0.3671	408.30	40
0.3669	408.74	45
0.3667	407.92	50

5 Conclusions

There are many ways to start an induction motor. The selection of the best method to use will be based on the starting current, the cost of the equipment.

5.1 DOL Results Conclusions

DOL starting in star or delta connection can generate high start current and torque which may cause electrical or mechanical problems with the supply or load, leading to inconvenience for users. The impact may not be significant for low-power motors.

5.2 Y-Δ Starter Results Conclusions

The star-delta starting method reduces the starting current and torque by 1/3 compared to the DOL method, as the motor windings are connected in a star configuration during the starting period and then reconfigured to a delta mode. This method is widely used to decrease start current and reduce disturbances on the electrical supply. DOL starting, on the other hand, has a maximum start current of 8–12 times load current and torque, which may cause electrical or mechanical problems with the driven load.

5.3 Autotransformer Starter Results Conclusions

The auto-transformer method reduces the initial voltage and starting current to 1/4, and can adjust current and torque to the required value by tapping on the auto-transformer. It is more expensive but limits high starting current and voltage more efficiently than the DOL and star-delta starters.

5.4 Soft Starter Results Conclusions

Soft starters provide a smooth and controlled acceleration for electric motors, reducing stress and line current during startup. Compared to direct starting or star-delta starters, soft starters have lower starting currents due to the smooth acceleration time. This method reduces the load on the motor and equipment, and results in a reliable and accurate startup process. However, soft starters may have a stationary delay and require external equipment, and the voltage applied to motor windings may vary.

5.5 Variable Frequency Drive starter Results Conclusions

We note the drive has the lowest starting current, the current started with small values, and began to rise gradually until it reached the load current. The starting current was controlled and reduced by controlling the frequency and voltage entering the motor.

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