

Comparative Analysis on The Effect of Different Methods of Starting Three Phase Squirrel Cage Induction Motor

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Abstract- *Induction Motors are the most widely used electric motor, due to its reliability, robust nature and low cost. They are mostly used in household and in the industries. Their industrial application is due to their high torque to volume ratio, ruggedness and low maintenance characteristic which they possess. Induction motor draws a high starting current during starting period which effect on electromagnetic torque, speed and current are greater. The traditional methods of starting includes, Direct On-line (DOL), Star Delta (SD) and Auto-transformer (AT) starting, which control these parameters up to certain limits. This research work is about comparing the starting methods of three phase squirrel cage induction motor using Direct On-Line, Star Delta and Auto-Transformer starter. Squirrel cage induction motor has a peculiar problem which is a problem associated with its initial inrush of current. The method used in this study was “Experimental Method” were experiment was conducted in the laboratory on the various starting methods which was earlier mentioned and Direct On-Line (DOL), Star Delta (SD) and Auto-Transformer (AT) starters was used as the material and MATLAB Simulink was used to observed their output behaviour. Results was obtained and presented on tables and on bar-charts were various parameters on the respective machine was compared and the values of “voltage, current, speed and torque were observed and presented on bar-chart. Finally, the study carried out shows that induction motors has a high initial starting current, and over coming this problem, a starting controller has been introduced in phase with the stator of the motor at the point of start to reduce that initial inrush of current.*

Indexed Terms- *Induction motor, electric motor, three phase squirrel, direct-on, star-Delta*

STATEMENT OF THE PROBLEM

Induction motor starting is a highly dynamic process that can have many adverse effects on the entire power system. Two of the prominent issues are the effects caused by high inrush currents on the mechanical system of the load, and the response of the generation source to the load step, of which voltage dip is of most concern. To address these issues, different starting methods has been developed to mitigate damaging effects. It is not economically practical to test each of these methods on a physical system because of possible equipment damage, electrical system vulnerability, and other problems

I. INTRODUCTION

The three-phase induction motors are the most widely used electric motors in the industry. They run at essentially constant speed from no-load to full-load. Nevertheless, the speed solely depends on the frequency and thus these motors are not effectively adjusted to speed control. We normally consider D.C motors when huge speed varieties are required. (Mehta & Mehta 2012) Starting induction motors on isolated or weak systems is a highly dynamic process that can cause motor and load damage as well as electrical network fluctuations. Mechanical damages are related with the high initial current drawn by an inclining induction motor. To add to the mechanical load increment, the voltage of the electrical system diminishes. Different starting methods can be applied to the electrical system to reduce these and other starting method issues.

The stator of an induction motor consists of 3-phase windings, which when connected to a 3-phase supply creates a rotating magnetic field. This will connect and cut the rotor conductors which thusly will initiate a

current in the rotor conductors and make a rotor attractive field. The attractive field made by the rotor will interface with the turning attractive field in the stator and produce revolution.

- OBJECTIVES

- i. Study the starting methods of induction motor when it's connected with different starter at the time of starting.
- ii. Analyze the starting current, torque and speed of induction motor when it is started with the help of direct-on-line, star-delta and auto-transformer starter.
- iii. Use MATLAB SIMULINK, to compare their corresponding output behavior.

- LITERATURE REVIEW

Mohamed and Subburaj. (2016) in their research demonstrated an experimental setup that utilizes a soft starting technique with extinction angle AC voltage controller and a speed stator current based closed loop scheme using Artificial Neural Network (ANN) and Fuzzy Logic Control to reduce the inrush current in the induction motor.

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Watanabe et al. (2019) noted that the Three-phase squirrel-cage induction motors (IMs) have been widely used as power sources for many electrical machines since a long time. Therefore, Cost reduction of IMs is urgently required. Cost reduction can be realized when concentrated winding (CW) is applied to an IM.

Simba et al. (2020) Their paper presents two methods for estimating the electrical parameters of the equivalent circuit of a 2-hp, three-phase, squirrel cage induction motor from direct starting voltage and transient current measurements. The first method is the application of conventional tests under the IEEE Std. 112. The second method is based on nonlinear optimization techniques using the

MATLAB/Simulink parameter estimation toolbox.

Yetgin (2020) In induction motors, the leakage reactance values are obtained from the motor short circuit operation experiment. However, these values do not give clear results for different geometries. For this reason, taking into the parameters of the slot geometry accounts for determining the stator and rotor leakage reactance values that are important in terms of obtaining more accurate results. His paper has investigated the stator slot permeance values of nine different stator slot structures commonly used in industrial type of three-phase squirrel cage induction motors for obtaining the best starting torque. The stator inductance and leakage reactance values were calculated for each stator slot structure.

II. MATERIALS AND METHOD

- Materials

- i. Direct on-line starter
- ii. Star delta starter
- iii. Auto-transformer starter

The stator of the two kinds of motors comprises of a three-stage balance distributed winding with each phase spaced by 120 degrees from the other two-phases windings. This produces a rotating magnetic field when current moves through the stator. In a three-phase squirrel cage induction motor, the rotor comprises of longitudinal conductor bars which are shorted at circular conducting rings. Whereas, the wound rotor induction motor has a 3-phase balanced distributed winding even on the rotor side with as many numbers of poles as in the stator winding.

A three phase Induction Motor is Self-Starting. When the supply is connected to the stator of a three-phase induction motor, a rotating magnetic field is produced, and the rotor starts rotating and the induction motor starts running. At the time of starting, the motor slip is unity, and the starting current is very large. The three-phase induction motor may be started by connecting the motor directly to the full voltage of the supply. The motor can also be started by applying a reduced voltage to the motor when the motor is started. The torque of the induction motor is proportional to the square of the applied voltage. Thus, a greater

torque is exerted by a motor when it is started on full voltage than when it is started on the reduced voltage. Squirrel cage induction motor just before starting is similar to a poly phase transformer with a short-circuited secondary. If normal voltage is applied to the stationary motor, then, as in the case of a transformer, an initial current, to the turn of 5 to 6 times the normal current or the normal rated current, will be drawn by the motor from the mains. This initial excessive current is objectionable, because it will produce line voltage (The potential difference or the voltage across two phases) drop, which in turn will affect the operation of the other electrical equipment and the lights connected to the same line.

The operation of the motor can be explained as shown below: When three phase stator winding is energized from a three-phase supply, a rotating magnetic field is set up which rotate around the stator at a synchronous speed. The rotating field passes through the air gap and cut the rotor conductors, which as yet are stationary. Due to the relative speed between the rotating flux and the stationary rotor, emf are induced in the rotor conductors. Since the rotor circuit is shorted-circuited, currents start flowing in the rotor conductors.

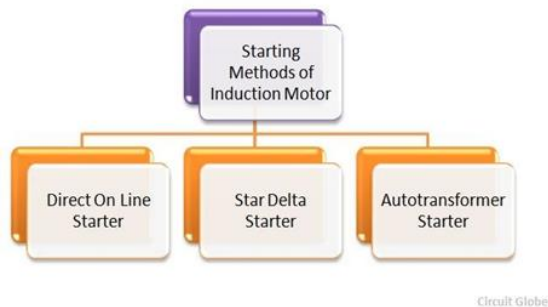


Fig. 1: Block Diagram Representation of the Three Basic Starting Methods of a Three Phase Squirrel Cage Induction Motor (Google 2021)

The initial rush of current is controlled by applying a reduced voltage to the stator (motor) winding during the starting period and then the full normal voltage is applied when the motor has run up to speed. For the small capacity motors say up to 3H.P, full normal voltage can be applied at the start. However, to start and stop the motor and to protect the winding from the over load current and low voltages, a starter is required in the motor circuit. In addition to this the starter

may also reduce the applied voltage to the motor at the time of starting. A 3-phase induction motors employ a starting method not to provide a starting torque at the rotor, but because of the following reasons:

- i. Reduce heavy starting currents and prevent motor from overheating.
- ii. Provide overload and no-voltage protection starter.

III. CALCULATION OF MOTOR CAPACITY

Induction motors are rated in kilowatt and are converted to horsepower for proper sizing of the electric motor and are stated in equation 3.5.

Motor capacity = 1.1Kw

$$\text{Converting to Horse Power (H.P)} = \frac{1.1kw}{746} = 1.5H. P \quad (5)$$

The input power is the power which comes in to the motor during the time of start and are represented with equation 3.6.

$$\text{Recall that } P_{in} = \sqrt{3} \times V \times I \times \text{Cos}\theta \quad (6)$$

$$KW = H.P \times 0.75kw$$

Equation 3.7. is express when the motor has been loaded and running on the rated load design for its operation.

$$HP \times 0.75kw = \sqrt{3} \times V_L \times I_L \times \text{Cos}\theta \times \text{eff} \quad (7)$$

Equation 3.8. denote the output power produced by the three-phase induction motor mostly when they are on load.

$$\text{Motor power output } (p_{out}) = \frac{2\pi NT}{60} \quad (8)$$

Equation .9. shows the power loss by the motor when it is running

$$P_V = P_{in} - P_{out} \quad (9)$$

Equation 3.10. shows the transformer ratio which relates the primary and the secondary voltage in their respective axis.

$$\frac{V_p}{V_s} = \frac{T_p}{T_s} \quad (10)$$

Star/Delta starters are probably the most common reduced voltage starters. They are used in an attempt to reduce the starting current applied to the motor during start as a means of reducing the disturbances and interference on the electrical supply.

Traditionally in many supply regions, there has been a requirement to fit a reduced voltage starter on all motors greater than 5H. P (4KW). The Star/Delta (or

Wye/Delta) starter is one of the lowest cost electromechanical reduced voltage starters that can be applied.

The Star/Delta starter is manufactured from three contactors, a timer and a thermal overload. The contactors are smaller than the single contactor used in a Direct On-Line starter as they are controlling winding currents only. The currents through the winding are $1/\sqrt{3}$ (58%) of the current in the line.

There are two contactors that are close during run, often referred to as the main contractor and the delta contactor. These are AC3 rated at 58% of the current rating of the motor. The third contactor is the star contactor and that only carries star current while the motor is connected in star. The current in star is one third of the current in delta, so this contactor can be AC3 rated at one third (33%) of the motor rating.

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There are two contactors that are close during run, often referred to as the main contractor and the delta contactor. These are AC3 rated at 58% of the current rating of the motor. The third contactor is the star contactor and that only carries star current while the motor is connected in star. The current in star is one third of the current in delta, so this contactor can be AC3 rated at one third (33%) of the motor rating.

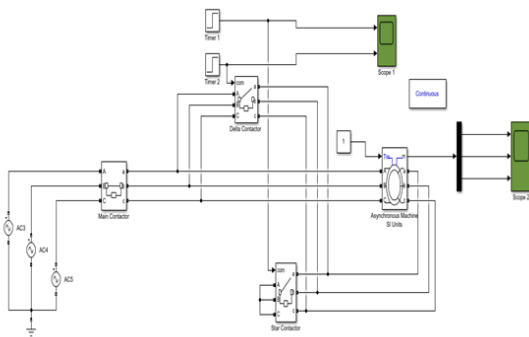


Fig. 10: Shows the Simulink model of star delta starting method of a three-squirrel induction motor

In this Simulink model, an induction motor of 1.5 H. P (1.1kw), 400v, at 50Hz frequency has been used. In this model, first star contactor will operate and after 0.16 seconds delta contactor will operate, making star to close. A timer has been used to operate both the contactor at a specific time automatically.

• Auto-transformer Starting Method

The auto transformer is used to limit the starting current of the three-phase squirrel cage induction motor, auto-transformer also uses tap changes to reduce the low voltage as needed on the low side connected to the motor terminal. Therefore, the current can be reduced during start-up; however, the torque is also reduced as the square of the voltage and needs to be taken into consideration to ensure enough torque is supplied during acceleration. As the motor speeds up, the line is switched to the full voltage. Common taps range from 50- 80%. The above starters are used for squirrel cage induction motor rotor.

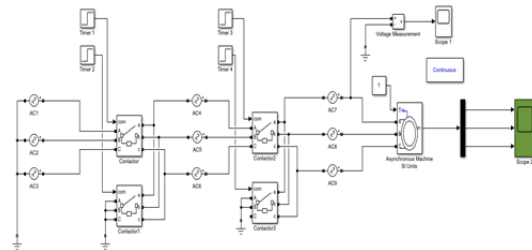


Fig. 11: Shows the Simulink model of an auto-transformer starting method of a three-phase squirrel cage induction motor

In auto-transformer Simulink model, a three-phase squirrel cage induction motor is used of capacity 1.5 H. P (1.1kw), 400v at 50Hz frequency. In this model, a variable voltage is applied at different stages so that they can operate and work as auto-transformer.

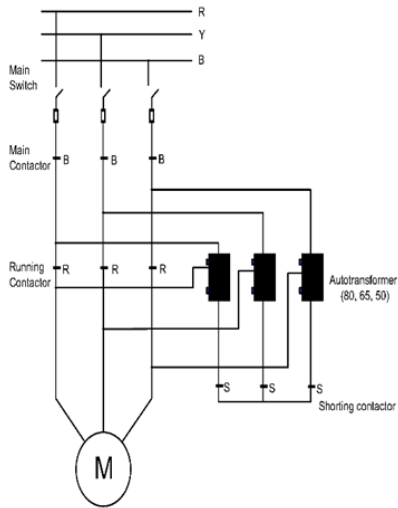


Fig. 12: Schematic Diagram of Auto-Transformer Starting Method of a 3-Phase Squirrel Cage Induction Motor



Fig. 13: Laboratory picture of Auto-Transformer Starting Method of a three-phase Squirrel Cage Induction Motor (Electrical Machine Laboratory Rivers State University 2020)

The picture shown in figure 3.3a above is the picture of an auto-transformer starter where the values of three phase voltage were obtained from. It also shows the wiring configuration of the auto-transformer where the connection was done from the three-phase power supply through a three-phase fuse to three ammeters connected in parallel with the three-phase squirrel cage induction motor.

RESULTS

This work discussed in detail the results obtained and discussion of simulated results carried out during this

research work. Laboratory experiments were conducted and data was gotten which was used for the analysis of the variables and respective results were obtained and presented on the tables below.

- Comparison of Motor Parameters during Starting Period using different Methods

Data table for experiment carried out in Electrical Machine laboratory Rivers State

Data for Direct On-line Starting Method						
S/n	Average Current	Average Voltage	Torque			
1	IR (A)	3.0	URS(V)	380	N-M	7
2	IS(A)	2.8	URT(V)	400	N-M	7
3	IT(A)	2.6	UST(V)	420	N-M	7

University Port-Harcourt.

Table 1. Direct On-line Starting Data

Table 1. This figure shows the data gotten from the experiment carried out on a three-phase squirrel cage induction motor when a direct on-line starter was used, the above variables of voltage, current speed and respective torque values were obtained and the below corresponding output chart were drawn using MATLAB Simulink software at the output of the system.

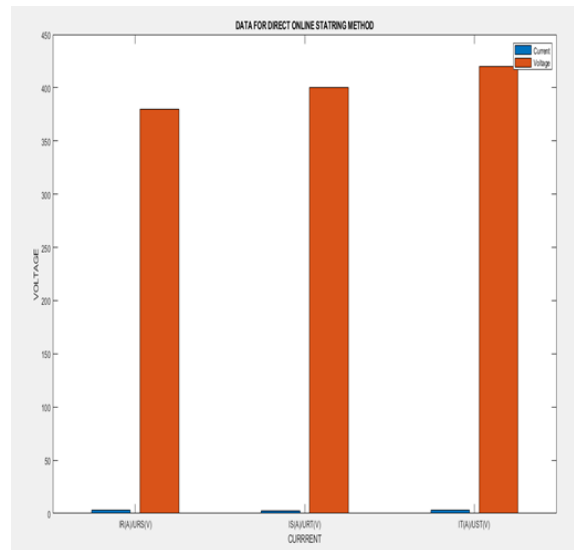


Figure 1: Chart of Direct On-line starting Method

Figure 4.1. shows the data of direct on-line method of starting a three-phase squirrel cage induction motor, corresponding values of voltage, current, speed and torque were realized from the experiment carried out in Electrical Engineering laboratory (Machine Lab) Rivers State University, were the average voltage value gotten during experiment was plotted against average current which was shown in the chart presented in figure 1. It was observed that the increase in voltage leads to the corresponding decrease in current.

Table 2: Star Delta Starting Data
Data for Star Delta Starting Method

S/n	SI Unit	Star Connection	Delta Connection
1	UN(v)	380	380
2	Nm(rev/min)	1340	700
3	IA(A)	2.8	2.76
4	MÄN(N-M)	7	3.8

Table 2. above shows the data gotten when star delta starter was used on the three-phase squirrel cage induction motor, and the above data were realized, which was also used in MATLAB environment for the realization of the bar chart below.

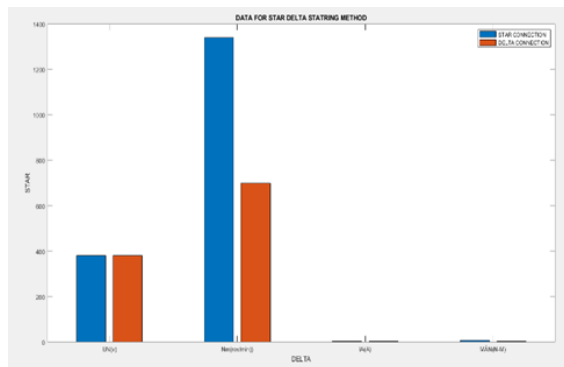


Figure 2: Chat of Star Delta

From the above chart of star delta method of starting a three-phase squirrel cage induction motor, corresponding data were gotten from the squirrel cage induction motor in the laboratory experiment which is presented in the chart of Figure 2. present a chart of star values which was plotted against delta corresponding values which shows the behavior of the

motor when running on star connected and eventually turned to delta.

Table 3. Auto-Transformer Starting Data

Data for Auto -Transformer Starting Method							
S/n	Primary Turns	Primary Voltage	Secondary Turns	Secondary Voltage			
1	861 T	380 V	12 T	5.29 V			
2	861 T	380 V	24 T	10.59 V			
3	861 T	380 V	48 T	21.18 V			
4	861 T	380 V	60 T	26.48 V			
5	861 T	380 V	132 T	58.26 V			
6	861 T	380 V	138 T	60.91 V			

Table 3. present a clear display of the primary turns, primary voltage, secondary turns and secondary voltage as data of the auto-transformer starting method of the three-phase squirrel cage induction motor. Three phase voltages were induced into the primary of the transformer, primary turns were kept constant and the respective secondary turns revolved round when the secondary voltage were determine.

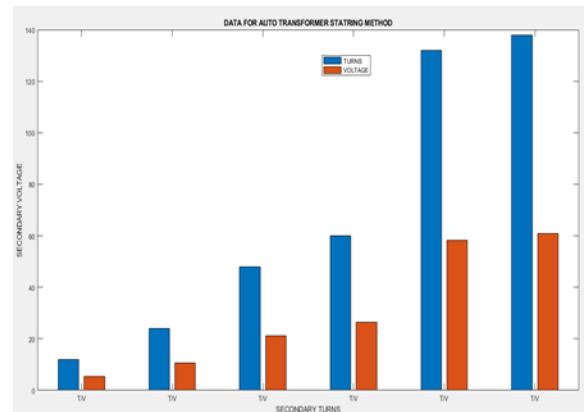


Fig. 3: Chat of Auto-Transformer

Figure 3. represent the data and information gotten from the experiment carried out on an Auto-Transformer in Electrical Engineering Laboratory RSU Port Harcourt were corresponding input voltages were gotten from a variac into the primary winding of the transformer before the respective secondary voltages and current was achieved. The behavior of the above chart shows proportionality in the data presented on the Auto-Transformer table. It was

observed that as the number of turns increased the secondary voltage also increased

Table 4. shows the corresponding values of load in kilowatt, voltage in kilowatt, and current in kilowatt which represent uniformity of the three-phases. The converted was done to enable all the three variables to be in kilowatt, which was all gotten from the three-phase squirrel cage induction motor when the load, voltage and current characteristic were merge together to see their output behavior.

Table 4. Data of the Merge Result

DATA OF THE MERGE RESULT

Load [kw]	Voltage [vavr] [kw]	Current [A] [kw]
0.06	0.42	0.14
0.05	0.40	0.13
0.04	0.38	0.12
0.03	0.36	0.11
0.02	0.34	0.10
0.01	0.32	0.09
0.003	0.30	0.08
0.002	0.28	0.07
0.003	0.26	0.06

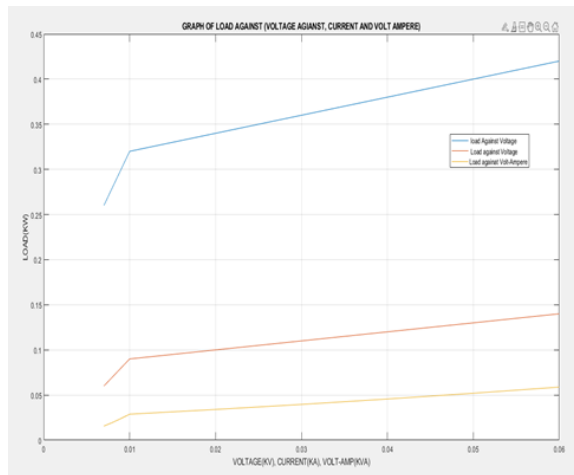


Figure 4: Graph of Load Again (Voltage, Against Current and Against Volt Ampere) and the Comparison of Output behavior of Different Starting Methods of Three Phase Squirrel Cage Induction Motor

Figure 4 shows the corresponding behavior of the characteristic of load against voltage, load against

current and load against volt ampere. The shunt capacitor can have a significant impact on the starting power factor but has sizing limitations based on the parameters of the induction motor. It is also able to slightly decrease the voltage drop and therefore slightly increase the inrush torque and current, and therefore slightly reduce the starting time. The star-delta (wye-delta) and auto-transformer approaches can be grouped together because of their similar effects through proportional reduction of the terminal voltage. The important tradeoff among these methods is the reduced inrush current to the reduced starting torque. Ensuring sufficient starting torque and the starting time are important considerations. The simulation tool provides a solid foundation for comparatively analyzing the starting methods, so that the starter choices can be narrowed down based on the user's specific desired value.

CONCLUSION

After the comparative analysis on the effect of different methods of starting a three phase squirrel cage induction motor and considering the laboratory experiments carried out and the respective input voltage and the corresponding output behavior of the model and charts gotten from the spontaneous behavior of the system, it is concluded that the starting torque of Direct On-Line D-O-L starter is very high as compare to the starting speed of the same Induction motor when connected to star delta and Auto-Transformer starter.

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