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# Minimization of Starting Torque and Inrush Current of Induction Motor by Different Starting Methods using MATLAB/SIMULINK

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**ABSTRACT**

Induction motors are considered nowadays the most commonly used electrical machines, which are mainly used as electrical induction motors and sometimes as generators. This is mainly due to the simplicity of composition, low price, light weight, high reliability, easy to command and control performance and not containing parts that could easily breakdown compared with DC machines and synchronous machines. Starting the IM is the most important and dangerous step, where the motor properties play a major role in the evaluation of all electrical motors, and these properties are defined by the following factors:

Starting torque. starting current. transient state. smoothness of the starting, simplicity and economics of starting.

In this paper, three different methods of starting three-phase Induction Motor are discussed and compared through curves of currents, torque, speed. These methods are Direct On Line, Auto Transformer, Star-Delta, for a constant power load condition. Simulation is made in MATLAB/SIMULINK and comparatively results are estimated to evaluate the best starting method for different range of induction motor rating.

***KEYWORDS:*** *Induction motor (IM), Direct on line (DOL), Auto transformer (AT), Star-delta (Y-D), Starting Torque, Inrush Current*

## I. INTRODUCTION

A 3-phase induction motor is theoretically self-starting. 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 link and cut the rotor conductors which in turn will induce a current in the rotor conductors and create a rotor magnetic field. The magnetic field created by the rotor will interact with the rotating magnetic field in the stator and produce rotation. Based on the construction of the rotor, a 3-phase induction motor can be categorized into two types:

1. Squirrel Cage Induction Motor
2. Wound Rotor or Slip Ring Induction Motor

The stator of both types of motors consists of a three phase balanced distributed winding with each phase mechanically separated in space by 120 degrees from the other two phase windings. This gives rise to a rotating magnetic field when current flows through the stator. In squirrel cage IM, the rotor consists of longitudinal conductor bars which are shorted at ends by circular conducting rings. Whereas, the wound rotor IM has a 3-phase balanced distributed winding even on the rotor side with as many number of poles as in the stator winding.

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 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 3HP, 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. Starter

Function of starter is to limit the starting high current to a safe value. The magnitude of induced emf depends upon the flux linking with the rotor conductors and its relative speed. The strength of the rotor flux depends upon the applied voltage. At the instant of applying rated voltage to the stator winding, rotor is stationery and as such the ship is unity. So if full rated voltage is given to the stator winding, then the magnitude of the emf induced in the rotor conductors will be high, because the relative speed between the rotor conductors and stator revolving flux is very high i.e. equal to the synchronous speed of the stator flux. Further the rotor conductors are short circuited and thus have low impedance. Hence, the current drawn by the stator winding or motor is very large, approximately 5 to 7 times the full load current.

There are three types of conventional starters:

1. Direct-On-Line starter
2. Auto-Transformer Starter
3. Star-Delta Starter

## II. DIRECT-ON-LINE STARTER

This is an ideal type of starting, simple and economical. In this type the full voltage is applied across the stator windings. The torque developed by the motor is maximum. The acceleration is fast and the heat of starting is low as seen figure 1.

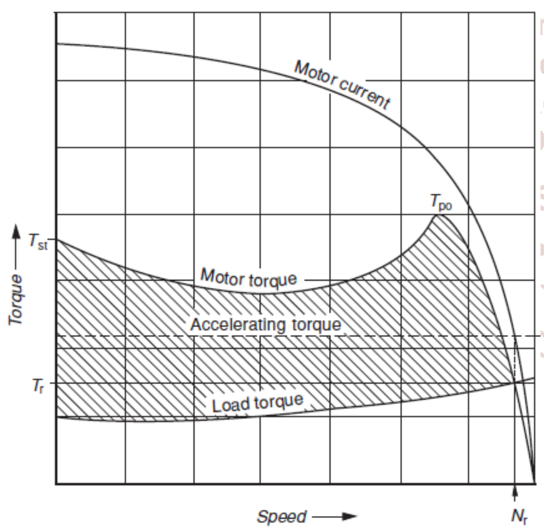



Figure1. Speed – Torque Curve in DOL method

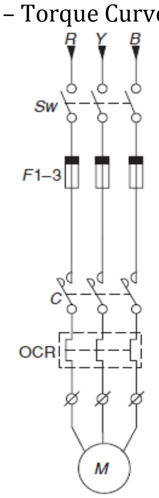



Figure2. DOL Connections

Figure 2 shows the connection diagram. For heavy rotating masses, with large moments of inertia, this is an ideal switching method. The only limitation is the initial heavy inrush current, which may cause severe voltage disturbances to nearby feeders (due to a large *I*st.*Z* drop). However, the method of DOL switching for larger motors is recommended only where the supply source has enough capacity to feed the starting kVA of the motor, with a voltage dip of not more than 5% on the LV side. Soft starting through a solid-state device are costly propositions. Autotransformer starting is also expensive due to the cost of its incoming and outgoing control gears and the cost of the autotransformer itself. This is not the case with *Y*/D starting. But, *A*/*T* and *Y*/D startings are reduced voltage startings and influence the starting torque ofthe motor. It is possible that the reduced starting torque may not be adequate to drive the load successfully and within the thermal withstand time of the motor. Unlike in smaller ratings, where it is easy and economical to obtain a high *T*st characteristic, in large motors, achieving a high *T*st, say, 200% and above, may be difficult and uneconomical. With the availability of large contactors up to 1000 A and breakers up to 6400 A, DOL starting can be used for LV motors of any size, say, up to 600 h.p. The use of such large LV motors is, however, very rare, and is generally not recommended. Since large electrical installations are normally fed from an MV or HV network, whether it is an industry, residential housing, an office or a commercial complex, DOL switching, even when large LV motors are used, may not pose a problem or cause any significant disturbance in the MV or HV distribution network. It is, however, advisable to employ only MV motors, in large ratings.

## III. AUTO-TRANSFORMER STARTER

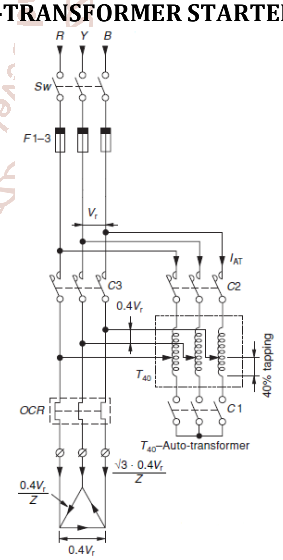



Figure 3. Auto-transformer Connections

An Auto Transformer is a transformer with only one winding wound on a laminated core. An auto transformer is similar to a two winding transformer but differ in the way the primary and secondary winding are interrelated. A part of the winding is common to both primary and secondary sides. On load condition, a part of the load current is obtained directly from the supply and the remaining part is obtained by transformer action. An Auto transformer works as a voltage regulator**.** There are two types of auto transformer based on the construction. In one type of transformer, there is continuous winding with the taps brought out at convenient points determined by desired secondary voltage and in another type of auto transformer, there are two or more distinct coils which are electrically connected to form a continuous winding.

For smoother acceleration and to achieve a still lower starting current than above, this type of switching, although more expensive, may be employed. In this case also the starting current and the torque are reduced in a square proportion of the tapping of the autotransformer. The normal tapping's of an autotransformer are 40%, 60% and 80%. At 40% tapping the starting current and the starting torque will be only 16% that of DOL values. At 40% tapping, therefore, the switching becomes highly vulnerable as a result of greatly reduced torque and necessitates a proper selection of motor.

To determine the tapping of the autotransformer: Consider an autotransformer with a tapping at 40%. Then by equating the powers of the primary and the secondary sides of the autotransformer

$\sqrt{3} \times V_L \times I_{AT} \times \cos\theta = \sqrt{3} \times (0.4\, V_L) \times (\sqrt{3} \times (0.4\, V_L / Z)\cos\theta$

Or $I_{AT} = 0.4^2 \times \sqrt{3} \times (V_L / Z)$ (1)

While starting current on DOL is: $I_{DOL} = \sqrt{3} \times (V_L/Z)$

$I_{AT} = 0.4^2\, I_{DOL}$ (2)

i.e. proportional to the square of the tapping, where

IAT = starting current on an autotransformer switching IDOL = starting current on a DOL switching

Z = impedance of the motor windings referred to the stator side per phase.

Generalizing the above equation, autotransformer tapping for a particular starting current. From this equation, the desired tapping of the autotransformer, to limit the starting current to a desired value can be determined.

$$\text{Tapping} = \sqrt{\frac{I_{AT}}{I_{DOL}}} \times 100\% \qquad (3)$$

From this equation, the desired tapping of the autotransformer, to limit the starting current to a desired value can be found. The Rating of autotransformer can be determined as follows:

Since an autotransformer is in the circuit for only a short period (during the start only), it can be short-time rated. The rating of the autotransformer can be calculated from

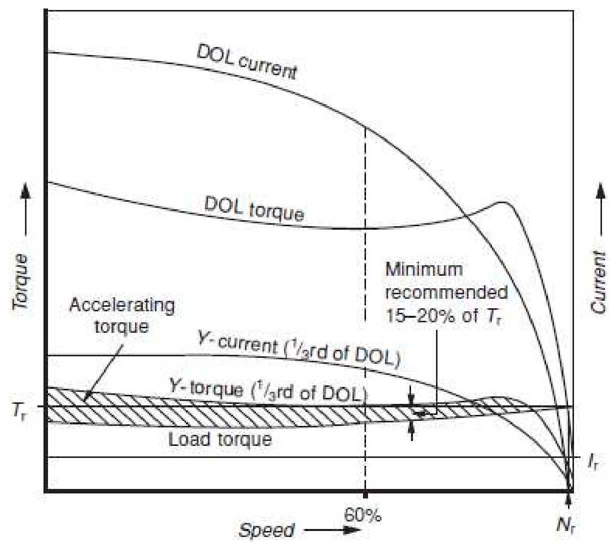
$$kVA = \sqrt{3} \times kV \times I_{AT} \quad (4)$$

where kV = applied voltage, and kVA(CMR) = continuous rating of the autotransformer.

Since the transformer will be in the circuit for only 15 to 20 seconds, the approximate short-time rating of the transformer can be considered to be 10–15% of its continuous rating. The manufacturer of the auto transformer would be a better guide to suggest the most appropriate rating of the transformer, based on the tapping and starting period of the motor.

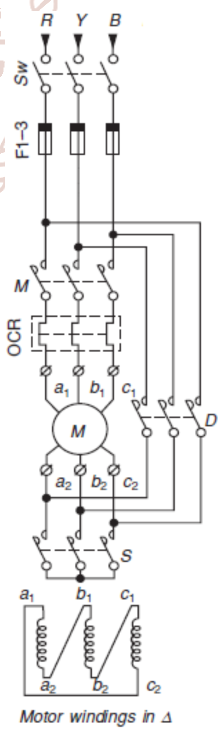
## IV. STAR- DELTA STARTER

The use of this starting aims at limiting the starting inrush current, which is now only one third that of DOL starting. This is explained in figure below. This type of starting is, however, suitable for only light loads, in view of a lower torque, now developed by the motor, which is also one third that of a DOL. If load conditions are severe, it is likely that at certain points on the speed–torque curve of the motor the torque available may fall short of the load torque and the motor may stall. During starting the motor windings are connected in star configuration and this reduces the voltage across each winding 3. This also reduces the torque by a factor of three. After a period of time the winding are reconfigured as delta and the motor runs normally.




Note Current jumps to almost DOL current even at around 60% speed, if switched to Δ position.

Figure4. Speed-Torque Curve in Start- Delta starter




Due to the greatly reduced Figure 5. Y-D Connection starting torque of the motor, the accelerating torque also reduces even more sharply and severely Figure 4. Even if this reduced accelerating torque is adequate to accelerate the load, it may take far too long to attain the rated speed. It may even exceed the thermal withstand capacity of the motor and be detrimental to the life of the motor. This aspect should be considered when selecting this type of switching. To achieve the required performance, it is essential that at every point on the motor speed–torque curve the minimum available accelerating torque is 15– 20% of its rated torque. In addition, the starting time must also be less than the thermal withstand time of the motor. This type of switching is limited to only LV system as MV motors are normally wound in star. However, in special cases, MV motors can also be designed for delta at a higher cost to the insulation system which may also call for a larger frame size. Also a provision can be made in the switching device to avoid the condition of an open transient during the changeover from *Y* to D. This type of switching requires six cable leads to the motor as against three for other types of switching's to accomplish the changeover of motor windings from *Y* to D*.*

## V. SIMULATION STUDY

The models regarding different starting methods were simulated in MATLAB/SIMULINK software. The motor ratings are taken from the pre-set MATLAB motors i.e. 4kW (5HP).

*For 4kW, 400V, 50Hz, 1430rpm:*

Rated Motor Torque, $T_m = \frac{P_{out}}{\omega} = \frac{4000\times 60}{2\pi\times 1430} = 26.72Nm$.

A constant Power load is applied over a period of 15sec simulation time amounting to the rated motor torque of 26.72 Nm so that rated speed is maintained. At no load, Ta = 1.5 (Tm-Tl)

Ta = 1.5*Tm = 1.5*26.72 = 40.08Nm.

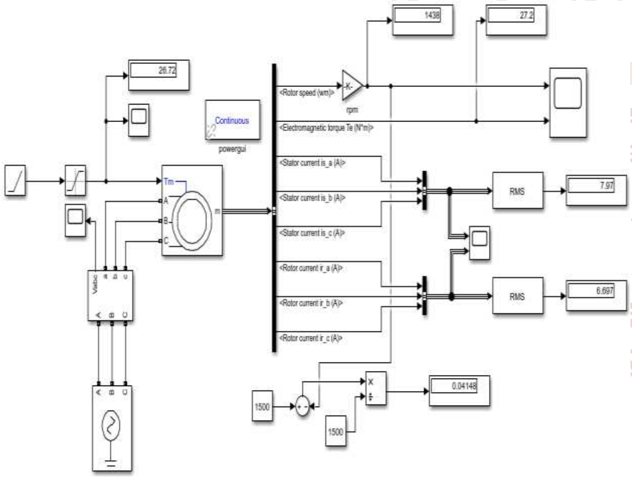



Figure6. DOL Simulation Diagram

The voltage source is 230V rms Voltage and full voltage is supplied in this starting method from the beginning.

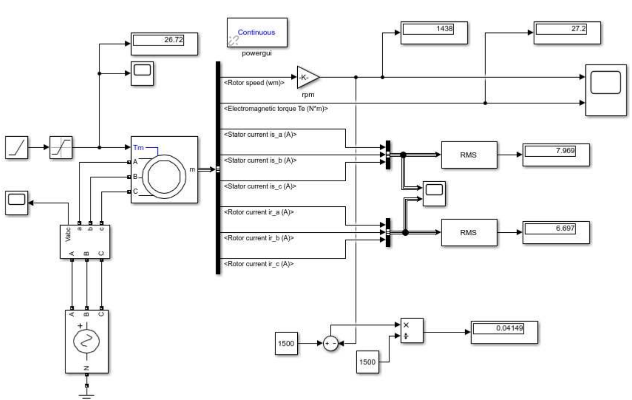



Figure7. Auto-Transformer Simulation Diagram

The voltage source used in this simulation diagram is "programmable voltage source" which is designed to work as an auto-transformer and slowly rise the voltage level from 0V to line voltage i.e. 400V. Hence, voltage is provided in small increments and thereby reduces the starting current as well as starting torque to a large extent.

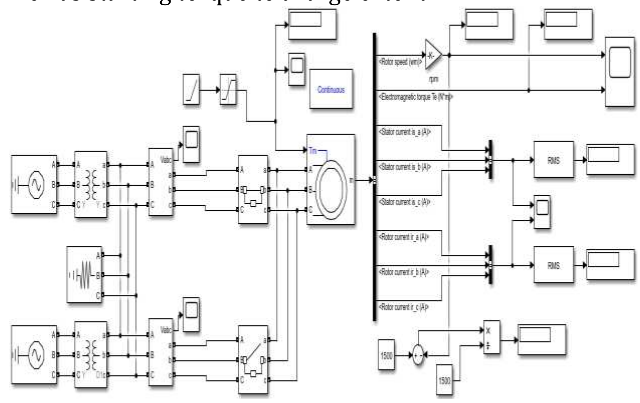



Figure8. Star-Delta Simulation Diagram

In figure 8 simulation diagram, two identical transformers are connected in parallel operation with two sources due to the fact that delta connected source is not available in MATLAB software. Therefore, the transformers act as a star source and delta source. Initially, star source is in operation and the circuit breaker is closed. After a stipulated time, the other circuit breaker is closed and the previous circuit breaker is opened leading to the delta source to be connected to the induction motor. Another buffer parallel resistance load is connected between transformers and induction motor to avoid MATLAB error of two current sources connected together.

## VI. WAVEFORMS

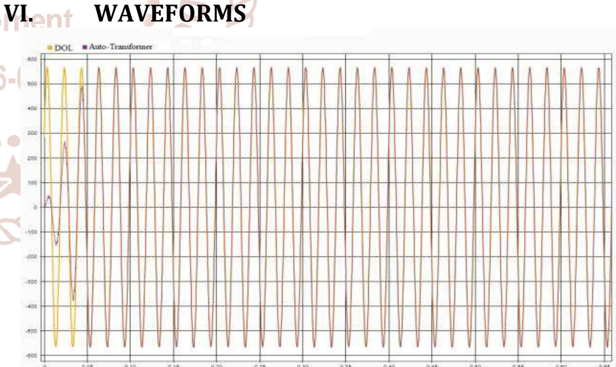



Figure9. Voltage waveforms DOL vs Auto Transformer


Figure10. Voltage waveforms Star-Delta

It can be observed in figure 9 that DOL has direct full voltage supply whereas auto transformer supplies voltage in increments in some time. Also, in figure 10, star source peak voltage is 326V which is 230V rms phase Voltage. Similarly, full voltage is supplied from delta source which is peak 565V which is rms 400V corresponding to the line voltage.

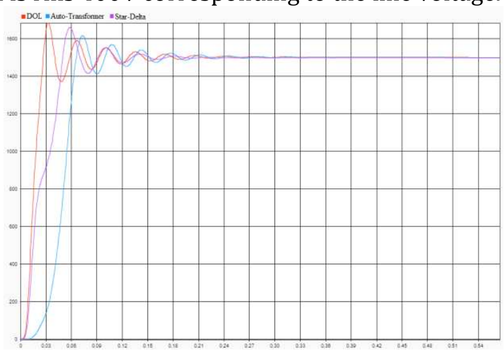



Figure11. Speed Curves of different starting methods

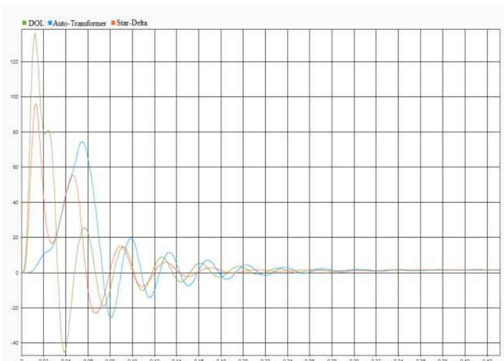



Figure12. Electromagnetic Torque of different methods

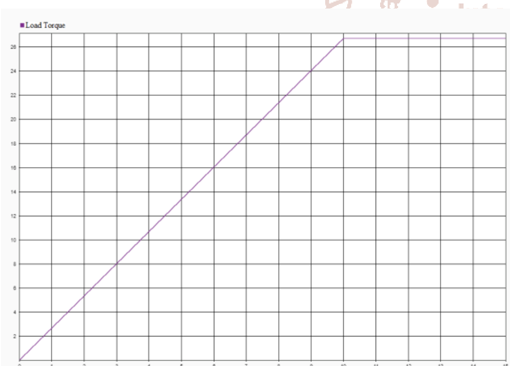



Figure13. Load Torque

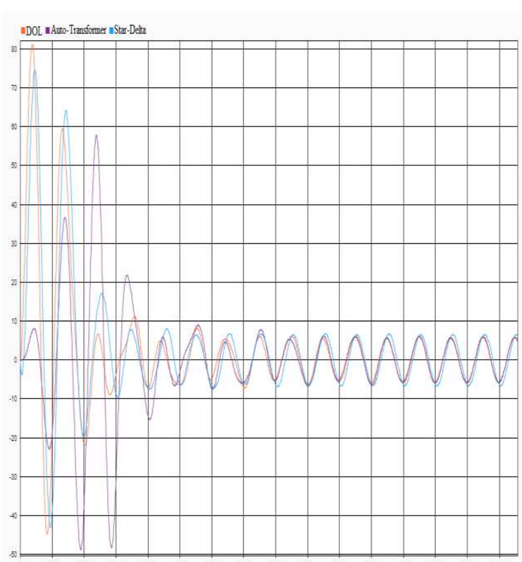



Figure14. Stator Current of different methods

The following list of tables are derived from the waveform analysis of all the three methods employed in MATLAB/SIMULINK software. The waveforms are computed, compared and analyzed.

TABLE I. VARIATION OF PARAMETERS WITH DIFFERENT METHODS

| Starting Method | DOL | Auto Transformer | Star-Delta |
|---|---|---|---|
| Starting Current (Stator) (A) | 80-60 | 25-20 | 55-40 |
| Starting torque (Nm) | 136 | 74.5 | 60 |
| Motor Heat During Start-up (J) | 440.06 | 43.76 | 211.82 |

TABLE II SETTLING TIMES FOR DIFFERENT METHODS

| Starting Method | DOL | Auto transformer | Star-Delta |
|---|---|---|---|
| Speed (rpm) | 0.4 sec | 1 sec | 0.25 sec |
| Electromagnetic torque (Nm) | 0.4 sec | 1 sec | 0.25 sec |
| Stator Current (A) | 0.15 sec | 1 sec | 0.1 sec |

## VII. CONCLUSION

Simulation Models for analysis of three different starting methods for induction motor were implemented in MATLAB/ SIMULINK software and waveforms regarding stator current, electromagnetic torque, speed was observed and noted. It is found that the best alternative for the present rating of motor i.e. 4kW is star-delta starter. This is due to the fact that auto transformer has a higher settling time as compared to star-delta and also a reasonably higher starting torque. This may prove to be a problem if the motor is started at some delicate load which requires very low torque. Also, starting current is lower as compared to DOL in star-delta but is still higher than Auto transformer starting. Motor heat-up is also lower than DOL but not auto-transformer starting. The switching transient also does not provide much disturbance in the speed obtained by the motor and has a better starting torque to even start-up at load condition if required. It is also observed that the rating of the motor plays a very important role in the selection of the starter. This is due to the fact that higher motor rating may require even lower starting torque and a different method may be employed in that case. Also, since solid-state switching i.e. soft starting is usually most expensive out of the conventional starting methods, it is not beneficial to lower the cost of starter as well as simplification of the methodology.

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