International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09 Issue: 12 | Dec 2022 www.irjet.net p-ISSN: 2395-0072

Comparative Analysis of Different Methods of Starting Induction Motor

Nana Twum Duah[1], **Isaac Kofi Otchere**[2], **Kwabena Amoako Kyeremeh**[3], **Joseph Owusu**[4]

[1]*Department of Computer and Electrical Engineering*
[2]*University of Energy and Natural Resources- Sunyani, Ghana*

***

Abstract - *Induction motors account for approximately 70% of all electric motors used for industrial purposes as a result of their versatility, robustness, reliability, low cost and high efficiency. However, induction motors have an undesirable characteristic of drawing high current during start-up. This necessitates special starting methods to monitor and control the starting current. The high starting current leads to issues such as a dip in the power system voltage which affects other systems and equipment connected to the affected power system. Various starting methods have been developed to overcome this problem. Six of these methods have been discussed and analyzed in this paper: Direct- on-line (DOL), Star-Delta, Autotransformer, Capacitor Starting and Soft Starting. A comparison of their current, torque, and speed are analyzed. Results obtain shows that an absolute conclusion cannot be made outright about one starting method being better that the other because there is a trade off in all these methods. Based on the analysis, a new starting method is proposed, which may eliminate the major deficiencies of the existing methods.*

Key Words: **Current, Induction motor, Soft Starting, Speed, torque.**

1. INTRODUCTION

ELECTRIC MOTOR accounts for large percentage of the generated electrical energy consumed. For instance, in the European Union, electric motors account for as much as 65%–70% of the consumed electrical energy [1]. Most of these motors are 3-phase squirrel-cage induction motors because of their reliability, robustness and relatively low cost [2]. In spite of their usefulness in industry, starting a 3-phase induction motor is of immense concern to the stability of a power grid. A 3-phase induction motor is theoretically self-stating, yet without any specialized starting mechanism, the current drawn at start can reach as high as 5-8 times the motor's rated current [3, 4]. Such large start current can destabilize the grid causing dip in the grid voltage and have a serious impact on the normal operation of other adjacent equipment such as lights, sensitive equipment etc. The start current may also have devastating effects on the stator winding and rotor bar, damaging the winding insulation [5, 6]. For these reasons, specialized starting methods have been developed. The 3-phase squirrel-cage induction motor (IM) may be started by supplying full voltage or reduced voltage [6]. Direct On-Line (DOL), Star-Delta and Autotransformer starting methods are commonly used in fixed speed applications as traditional electromechanical starters. Each starting method has its own merits and demerits which make one starting method preferred over the other. The basis for selection must be a thorough understanding of the power system constraints, the load to be accelerated and the overall cost of the equipment [3]. The starting current of the various starting methods is investigated in this paper using simulation models that aid in understanding the starting characteristics.

1.1 Three Phase Induction Motor

The starting method for a 3-phase induction motor is not to provide a high starting torque but rather reduce heavy starting currents and prevent motor from overheating. There are several general methods developed to address particular induction motor starting problems in terms of the motor size and the stability of the connected network.

In considering the factors taken into account in the design of the starting methods, it is realized that, trade-offs of certain factors may have to be introduced for a starting method to suite a particular application [7]. The various starting methods can be broadly categorized into conventional motor starters and electronic drives [8]. Conventional motor starters are often used in fixed speed applications and includes direct on-line, star-delta, shunt capacitor and autotransformer starter. DOL starter is the simplest and the most inexpensive of all the starting methods with a very large starting current, normally 6 to 8 times the rated current [5]. The starting torque is likely to be 0.75 to 2 times the full load torque [5]. DOL starter is used only for motors with a rating of less than 5KW [8]. Induction motors that are set up for star delta starter are built so that the leads from each end of each phase group are easily accessible. In this way the motor leads are initially connected in star and once the motor speed reaches about 70% of the rated speed, the power supply connection to the motor is changed to a delta thus giving it a full voltage. A major problem with the Star-Delta starter is the spike in current that occurs during transition from star to delta configuration. A closed transition starter is developed which employs series resistors to eliminate the current spike experienced by the open transition starter. However, the closed transition starter results in reduced torque and it does not provide speed control [9].

The autotransformer can be looked as an improvement of the star-delta starter. It uses tap changes to reduce the voltage available to the induction motor during start. This will proportionally reduce the starting current and the torque [5, 8]. The advantage of the autotransformer lies in the users' ability to select different tap values. With this, the user may change the tap to suit a particular application. However, the cost of installing an autotransformer is expensive compared to the other conventional motor starters. The induction motor requires large inductive current to operate which lags the applied voltage. Shunt capacitor starter acts to supply current that leads the voltage hence reducing the amount of reactive power required to be drawn from the power system. The shunt capacitance may be left connected if they are properly rated so as to provide power factor correction or removed as the motor approaches rated speed.

Electronic drives allow the stator input voltage to be gradually increase and hence the starting current. Soft starters may employ semiconductors, to reduce the initial start voltage of the induction motor resulting in lower motor torque. During the starting process, the soft starter progressively increases the motor voltage so that the motor generate enough power to accelerate the load to rated speed. The soft starter gradually increases the voltage from a pre-set level, as low as 0V, to the rated voltage. This causes very smooth start-up. However, this results in higher harmonics being injected into the system. The current limiting technique senses the current at the motor so that the firing angle can be controlled proportionately [10]. The soft starter adds significant flexibility in operation and interoperability, due to the fact that it is more sensitive to the mechanical load characteristics. This also results in lower maintenance cost and increased lifetime of the mechanical load, and can result in improved energy efficiency. However, the trade-off is the increased operational complexity, and soft starters are generally expensive devices [7, 8].

The paper is organized as follows: Section II describes the system modelling and its parameters. Section III highlights a brief description of the various motor starters using simulations and in Section IV, a number of case studies and discussions are outlined. and the conclusions are summarized in Section V.

2. SYSTEM MODELLING

The paper models three system primitives; three phase squirrel-cage induction motor, induction motor starting control circuit and a grid connected busbar system in Fig. 1. The IM is modeled with ETAP® (Electrical Transient Analyzer Program) as a 373kW 4kV dynamic machine using the predefined circuit model MV500HP2P from ETAP® library in Fig. 2. Using a NEMA design type B, the model data describes the specific 373kW motor intended for acceleration in this study. The parameters of the three-phase IM is found in Table 1.

Table -1: THREE PHASE IM PARAMETERS

Model Data	Rs(Ω)	Xs(Ω)	Xm(Ω)	Xrlr(Ω)	Xrfl(Ω)	Rrlr(Ω)	Rrfl(Ω)
	3.832	10.29	365.2	9.3	11.67	1.23	1.52
Name Plate Data	KVA	FLA	% PF	% Eff	%NLA	Inertia kgm²	Torque ft-lb
	434	62.7	92.08	93.22	26.63	0.793	1481.9

2.1 Modelling of Motor Load

The connected load is modeled as a simple fan with the characteristic torque equation expressed in percentage as in (1). The motor characteristics is shown in Fig. 3.

$$\text{Load Torque} = 10 - 91w + 321w^2 - 147w^3 \qquad (1)$$

where w is a variable.

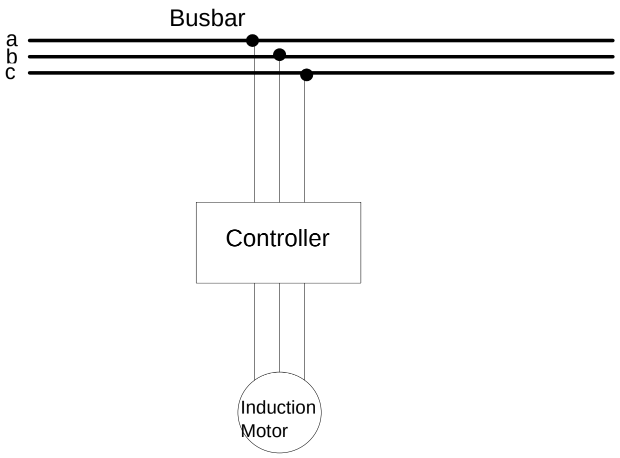

Fig. 1. System model

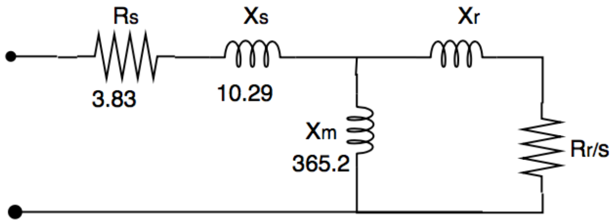

Fig. 2. Equivalent circuit of three phase induction motor

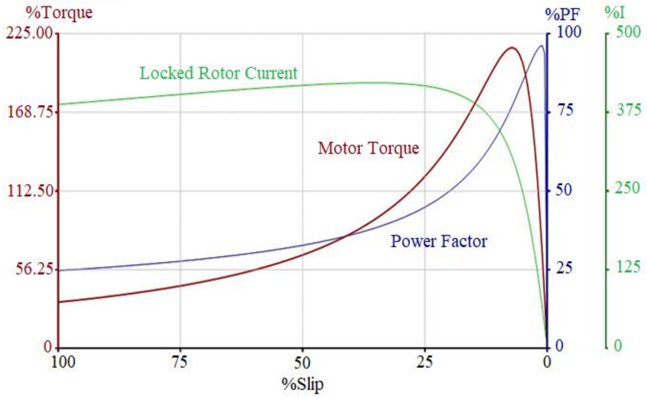

Fig. 3. Motor Characteristic

The load torque is defined such that it lies distinctly below the available machine torque so that under normal operating conditions, it will accelerate. The coupling of the fan to the motor is achieved by means of a simple coupling gear. The motor must not only develop adequate torque to overcome the fan load, but it must also have excess torque to overcome the inertia of the fan and accelerate it to speed within a desired amount of time. The coupling arrangement of the fan inertia (WR), coupling gear and the motor inertia is modeled as in (2).

$$WR_{ms}^{\ 2} = WR_{fs}^{\ 2}\left(\frac{n_f}{n_m}\right)^2 \qquad (2)$$

where:

WR_{ms} : Inertia of fan load referred to motor speed.

WR_{fs} : Inertia of fan load plus drives

n_f : Speed of fan. n_m: Speed of motor

ETAP uses the motor inertia (H) to generate corresponding data for fan inertia in order to study the acceleration when the value of H is manually inserted as shown in Table. 2.

TABLE 2: MOTOR COUPLING CHARACTERISTICS

	Motor	Coupling	Load	Total
RPM	1800	1800	1800	1800
WR^2	118	59.02	295.1	472.1
H	0.198	0.099	0.496	0.793

3. Motor Starter Simulation

Five starting methods are implemented with ETAP but the individual control circuits are all designed and simulated with automation studio. Data from ETAP is exported to MATLAB to plots the graphs. Graphs of current, torque, speed with time are shown with all the various starting methods. All the other methods are compared to DOL method.

A. *Direct-on-line Starting*

DOL is implemented with a direct connection of the motor terminals to the power source through a single contactor in fig. 4. The motor draws a very high inrush current. However, as the motor accelerates, the current begins to drop, but until the motor is at a high speed, typically about 85% of synchronous speed.

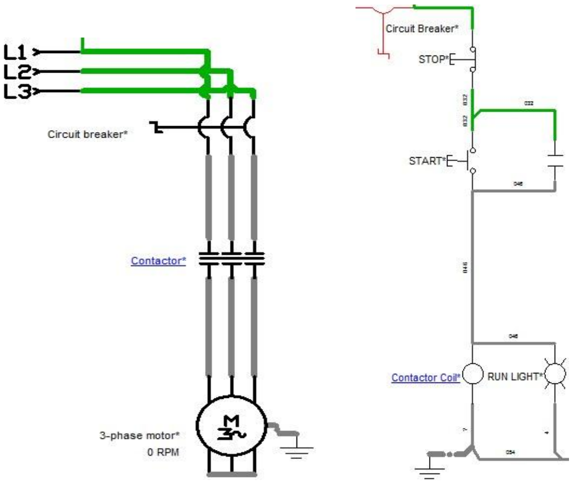

Fig. 4. Motor Circuit Connection

B. *Star – Delta Start Method*

The motor terminals are connected in the star pattern initially reduces the line voltage by 57.7% and then the full line voltage is applied in delta connection after the motor achieve 85% of the rated speed. The connection is shown in Fig. 5.

C. *Capacitor start Method*

The connection of this starter is demonstrated in fig.6. The motor is first started in a single phase mode with the help of a properly selected phase balancer capacitor and then switched to normal three phase operation once its speed reaches 70% of the rated speed.

D. *Autotransformer start Method*

The motor is connected to the secondary side of the autotransformer while starting as in Fig.7. The taps on the autotransformer limit the voltage applied to the motor to 50%, of the nominal voltage and the line current is less than the motor rated current during starting.

E. Electronic Soft Start Method

Voltage ramping and limited current starting is used for the electronic soft starting. Pulse width modulation (PWM) is employed to trigger pulses to control the firing angle in order to achieve the desired voltage control. The variation of the firing angle limits the line voltage supplied to the motor terminals. Fig.8 depicts Allen-Bradley soft starter connection.

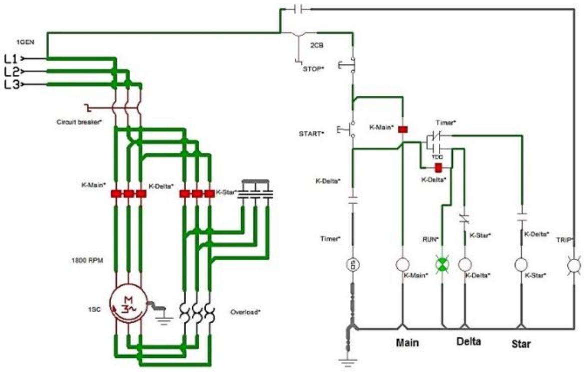

Fig. 5. Star Delta Start Method

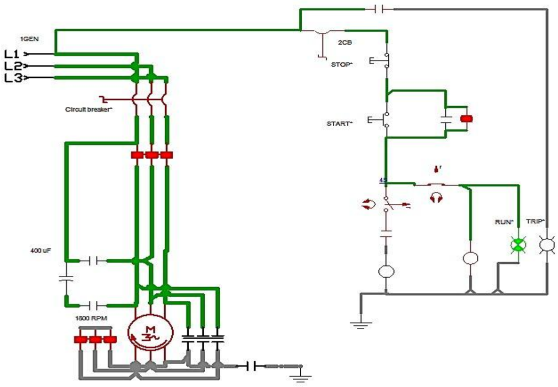

Fig. 6. Capacitor Start Method

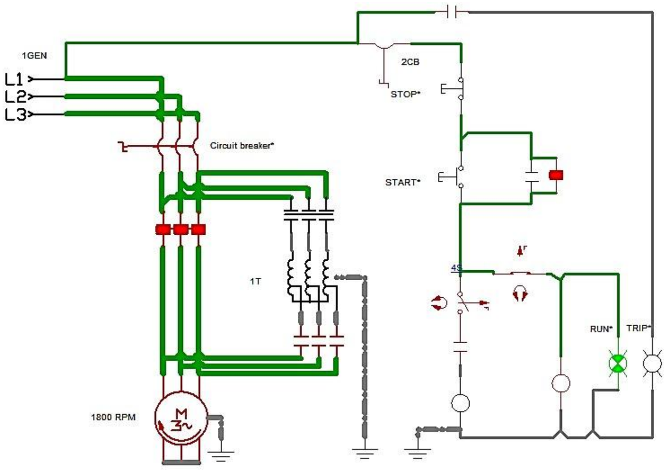

Fig. 7 Autotransformer start Method

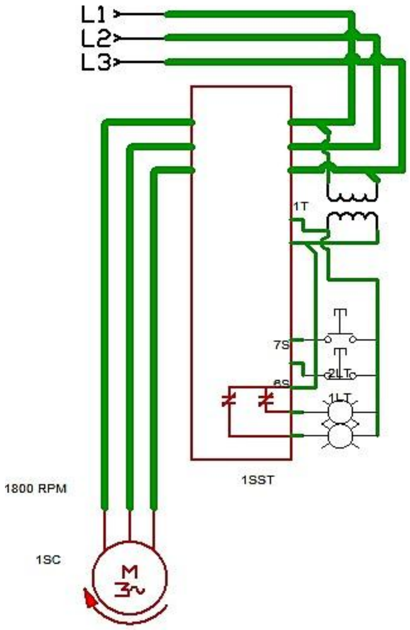

Fig. 8 Allen-Bradley soft starter

4. Results and Discussion

The resulting graphs of current against time for the five starting methods are given in Fig. 9. The starting current of star delta starter is approximately 175% of the full load current (FLC) as compared to DOL which is about 500%. In the case of autotransformer start, the current starts with about 125% of FLC. The current increases smoothly to 310% of FLC as the speed increases before the autotransformer is taken out of the circuit. Using the capacitor method, the current rises to approximately 380% of FLC. However, in the soft-start method, the current rises gently from 30% to 420% of the FLC when the voltage is ramped from 10% to 100% using a current limit of 750%. The current drops to the rated full load current after 18 seconds. Star delta and autotransformer starters have high inrush current during the switch over.

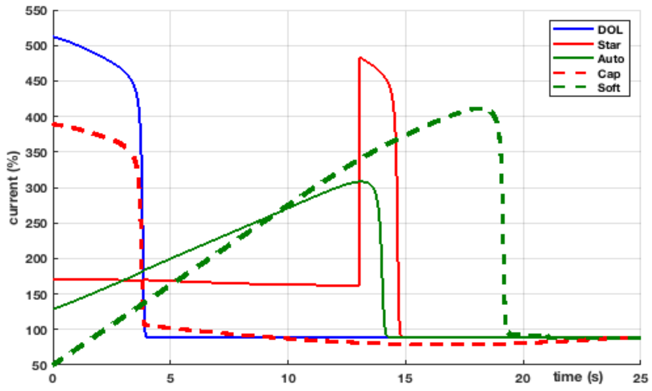

Fig.9. Starting currents

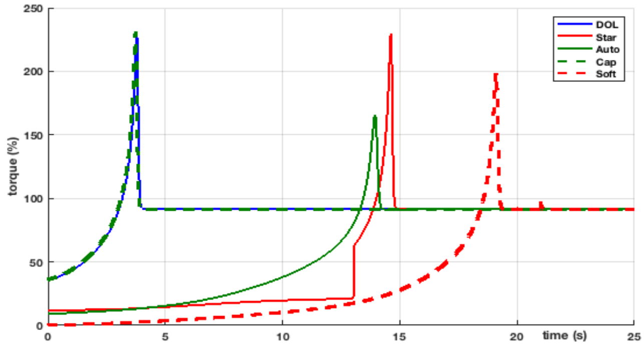

Fig.10. Starting torques

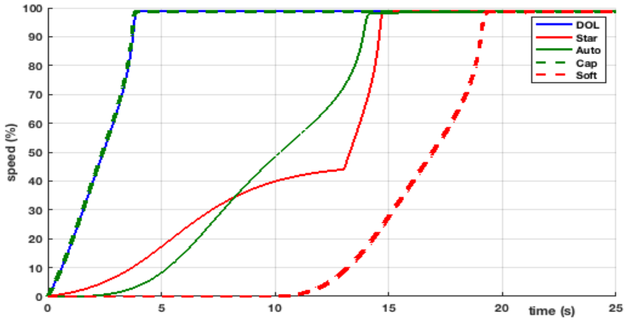

Fig. 11. Starting speeds

Fig. 10 shows graphs of starting torque with time for all the starting methods. Both Capacitor and DOL starting methods have similar torque characteristics. The starting torque of star delta is 30% of the rated torque. The torque of DOL and star delta rises sharply to the maximum torque with in 4s and 14s respectively. The corresponding starting torque for autotransformer method is approximately 10% of the rated torque; this increases gradually to 165% at 13s of the full load torque where the autotransformer is taken out of circuit. The resulting graphs of speed with time for all the five starting methods are shown in Fig.11 The speed of DOL and capacitor start reaches the rated speed with in 3s while it takes about 18s for electronic softer starter to reach the rate speed. Star delta starter and autotransformer starters takes almost the same time to reach the rated speed.

5. CONCLUSION

The starting characteristics of different starting methods for IM have been studied. Computer simulations provide flexible means to aid in the decision making of the best starting method to apply for specific applications. The simulation results indicate that, an absolute conclusion cannot be made outright about one starting method being better than the other unless their frame of comparison is justified. The star-delta, autotransformer and soft starter reduces the starting current significantly however the trade-off among these methods is the reduction in starting torque. The star-delta and autotransformer can also have disturbing switch-over transients. Also, increasing the firing angle of the soft starter reduces the starting current but increases the motor acceleration time. The results show that there is trade-off in all the different stating methods of IM.

It is observed that, all the starting methods try to bring the motor up to the rated speed. The difference in shape of the speed curve is as a result of, the various starting methods drawing different amount of current to bring the motor up to speed. It is projected that, if an external means is used to bring the motor's speed to at least 60% of the rated speed before connecting to the power source; the amps drawn will reduce proportionally. This knowledge can be implemented as a torque assisted method where smaller motor can be used to turn a higher rated motor at no load to about 60% of the motor's rated speed. The smaller motor is then decoupled from the set up and the higher rated motor connected to the power source. This method may eliminate the major differences in the discussed starting methods. Further work should be carried out on the proposed method of to achieve an efficient design.

REFERENCES

[1] A. Almeida, F. Ferreira, J. Fong, and P. Fonseaca, "EuP Lot 11 motors, ecodesign assessment of energy using products," University of Coimbra, Brussels, Germany, 2008.

[2] Almeida, P. Fonseca, F. Ferreira, F. Guisse, A.Diop, A. Previ, S. Russo, , "Improving the penetration of energy - efficient motors and drives," University of Coimbra, Brussels, Germany,, 2000

[3] S.K. Kim and T.K. Kim, "A Novel Hybrid Sequential start control system for large inductive loads," *Journal of Electrical Engineering & Technology,* vol. 10, no. 1, pp. 388-394, 201

[4] W.J. Horvath, "Concepts, Configurations & Benerfits of Motors Starting and Operation with MV AC Adjustable Speed Drives," IEEE *Cement Industry Techinical Conference*, pp. 258-274, 2008.

[5] "Tecnical Note Starting Method For AC Motors," ABB, 2010. [Online]. Available: http://bit.ly/2h1PoNw. [Accessed 11 11 2016].

[6] Y. Sangsefidi, S. Ziaeinejad, H. P. Nabi and A. Shoulaie "Induction motor control based on approximate stator flux," *IET Power Electronics,* vol. 7, no. 11, pp. 2765-2777, 2014.

[7] J.A. Kay, R.H. Paes, J. George Seggewiss and R.G. Ellis "Methods for the Control of Large Medium -Voltage

Motors: Application considerations and guidelines," *IEEE Transactions on Industry Applications,* vol. 36, no. 6, pp. 1688 - 1696, 2000.

[8] K. Pillay, M. Nour, K.H Yang, D.N.D Harun and L.K.Haw, "Assessment and Comparison of Conventional Motor Starters and Modern Power Electronics Drives for Induction Motor Starting Characteristics," 2009 *IEEE Symposium on Industrial Electronics and Applications*, ISIEA 2009-Pro., vol. 2, pp. 584-589, 2009.

[9] J. Bredthauer and N. Struck "Starting of large medium voltage motors design, protection and safety aspects" Proceedings of IEEE Petroleum and Chemical industry Technical Conference, pp. 141-151, 2002.

[10] Y. Xiao, "Research on System of Combining Soft Start and Doubly-Fed Speed Regulation," Advances in Information Sciences and Service Science, vol. 4, no. 18, pp. 181-188, October 2012.