Three Phase Induction Motor Starting Analysis Using ETAP

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Abstract— **Three phase induction motors are the most rugged and the most widely used machines in industry and agriculture. These motor are frequently started by connecting them directly across the supply line. It draws a large starting current from the supply line, about 5 to 7 times of the motor rated current. If this causes appreciable voltage drop in the supply line, it may affect other loads connected to the line. In addition, if a large current flows for a long time, it may overheat the motor and damage the insulation. Therefore, the motor bus voltage should be maintained at approximately 80 % of the rated voltage while starting. In this paper, ETAP (Electrical Transient Analyzer Program) is employed to investigate whether the starting motor can be successfully started under the operating conditions without starter. Moreover, one more objective of motor starting analysis is to present the use of VFD (variable frequency drive) and auto-transformer that devices can maintain the bus voltage and reduce the large starting current while motor starting on the system.**

Keywords— **motor starting analysis, VFD, auto-transformer, large starting current, three phase induction motor, ETAP**

I. INTRODUCTION

Three phase induction motors on modern industrial systems and agriculture applications are becoming increasingly larger. Some are considered large even in comparison to the total capacity of system's power. During the induction motor starting period, the starting motor appears to the system as small impedance connected to a bus. This motor draws a large current from the supply line, about 5 to 7 times of the motor rated current, which therefore results in voltage drops in the supply line and imposes disturbances to the normal operation of other system loads. As the induction motor acceleration torque is dependent on motor terminal voltage, in some cases the starting motor may not be able to reach its rated speed because of very low terminal voltage. This makes it necessary to carry out a motor starting analysis.

In this paper, dynamic motor acceleration is studied by using the ETAP (Electrical Transient Analyzer Program). In the dynamic motor acceleration study, the starting motors are modeled by dynamic models and the motor acceleration module simulates the entire process of motor acceleration. This method is used to investigate if a motor can be started and how much time is needed for the motor to reach its rated speed, as well as to find out the effect of VFD and auto-transformer at motor starting period.

II. THREE PHASE INDUCTION MOTOR STARTING

Three phase induction motors are theoretically self starting. The stator of this motor consists of three phase windings, which when connected to a three phase supply produces a rotating magnetic field. This will connect and cut the rotor conductors which in turn will induce a current in the rotor conductors and produce a rotor magnetic field. The magnetic field produced by the rotor will interact with the rotating magnetic field in the stator and produce rotation. Therefore, three phase induction motors employ a starting method not to provide a starting torque at the rotor, but to reduce heavy starting currents and prevent motor from overheating; there are many methods in use to start three phase induction motors. In this paper, auto-transformer starter method and variable frequency drive (VFD) method are used to study three phase induction motor starting (dynamic motor acceleration).

(A) Auto- Transformer Starter

This method reduces the initial voltage applied to the motor The motor can be connected permanently in delta or in star, is switched first on reduced voltage from a three phase tapped auto-transformer and when it has accelerated sufficiently, it is controled to the running (full voltage) position.

(B) Variable Frequency Drive (VFD)

VFD is an electronic motor starting device (commonly applied to pumps, fan, etc.). It controls by power electronic principles in varying the frequency of the input power to the motor thereby controlling the motor speed. This provides reduced motor starting current, reduction in thermal and mechanical stresses on motor and belts during starting, etc.

III. DESCRIPTION OF ETAP TO STUDY MOTOR STARTING

ETAP is the most comprehensive solution for the simulation, design and analysis of generation, transmission, distribution, and industrial power systems. In ETAP, each research project makes available a set of users, user access controls, and a separate database in which its elements and connectivity data are stored. All interface views are fully graphical and the engineering properties of each circuit element can be edited directly from these views. The results are displayed on the interface views. Generally, ETAP has three modes of operation under Network Systems; Edit, AC and DC Study. The AC Study mode consists of analysis such as load flow, motor acceleration, transient stability, short circuit, and protective device coordination.

For creating research project on motor starting studies, similar to load flow study ETAP requires selection of mode of operation of power sources, which are swing mode, voltage controlled mode, power factor controlled mode, Mvar controlled mode. After mathematical modeling of source model, load model and with appropriate selection of operating mode, different load flow method are used to find different electrical parameter at different bus. Methods are used for load flow and motor starting simulations to find different parameter are; (a) Accelerated gauss seidel (b) Newton-Raphson method (c) Fast decoupled method. Among three methods, Guess Seidel method is the simplest method but it is used for small networks. Numbers of iterations requires to converse it depends on number of bus and therefore it takes long time to converse and sometimes diverse also for big complex network. Newton-Rapson method is the unique choice for large industrial networks. It only takes 3 to 5 iteration to converse irrespective of numbers of bus. Newton Rapson methods some assumptions are made to simplified Jacobean simplified version of N-R method and give almost very approximate solutions. According to load flow analysis, buses are divided as generation and load buses where some parameters are specified such as power and voltage at generation bus and active and reactive power at load bus. One bus in the network keeps as swing or slack bus. Here, motor starting analysis is performed by simulating motor starting from 1 to 10 seconds to understand better starting scenarios.

To work in dynamic motor acceleration after creating the research project, follow these instructions: (a) Click the edit button and create the solution parameters for VFD and auto-transformer setting (b) to check the load flow, go to load flow mode by clicking the load flow analysis button with Newton-Raphson method on the mode toolbar. The load flow results is now displayed on the one line diagram and achieved from the report manager (c) Click the dynamic motor acceleration button on the motor acceleration analysis toolbar to see the alert view and study the results on the one-line diagram (d) Click the motor starting plot button to get the comparison results of three motors; motor 1 without starter, motor 2 with VFD, and motor 3 with auto-transformer. (e) Click the report manager button to view any part of the output report.

IV. CASE STUDY: DYNAMIC MOTOR ACCELERATION ANALYSIS USING ETAP

Fig. 1 shows one line diagram for dynamic acceleration analysis of three phase induction motor. In this figure, the parameters setting for transformers (T1, T2, T3), circuit breakers (CB1,CB2,CB3), cables (1,2,3) and three phase induction motors (Mtr1, Mtr2, Mtr3) are the same values respectively. The input data or parameters setting of this one line diagram are shown in Tables I to VIII. A system base of 100 MVA has been used for all studies. Base values of 12.47kV, 480V have been considered for various systems voltage level.

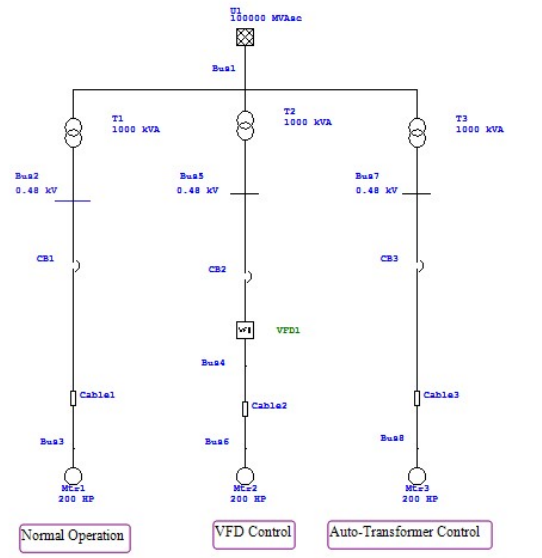


Fig. 1 One line diagram for 3-phase induction motor starting analysis

Tables I Machine Input Data

ID	Type	Rating (MVA)	kV	Connected Bus	Bus Type
U 1	Utility	100000	12.470	Bus 1	Swing Bus

Tables II 2-Winding Transformer Input Data

ID	Rating MVA	Pri. kV	Sec. kV	Standard	Attitude (m)	% Z	% X/R
T 1	1.0	12.47	0.48	ANSI	1000	5.75	5.79
T 2	1.0	12.47	0.48	ANSI	1000	5.75	5.79
T 3	1.0	12.47	0.48	ANSI	1000	5.75	5.79

Tables III Three Phase Induction Motor Data

ID	Type	Class	Model ID	Rating HP	kV	Load
Mtr1	SGL2	HV-HS-HT	LV200HP2P	200	0.48	PUMP
Mtr 2	SGL2	HV-HS-HT	LV200HP2P	200	0.48	PUMP
Mtr 3	SGL2	HV-HS-HT	LV200HP2P	200	0.48	PUMP

Tables IV Circuit Breaker Data

ID	Standard	Library Model	kV(max)	Pole	Inter kA	Size (Amp)	Ratd kV
CB 1	ANSI	MDL	0.6	3	50	600	0.48
CB 2	ANSI	MDL	0.6	3	50	600	0.48
CB 3	ANSI	MDL	0.6	3	50	600	0.48

Tables V Cable Input Data

ID	Library	Length (ft)	Phase
Cable 1	0.6 LALN3	100	3
Cable 2	0.6 LALN3	100	3
Cable 3	0.6 LALN3	100	3

Tables VI VFD Starting Device

ID	Motor	Type	Switching	Values %	V/HZ %	Ctrl Type
VFD	Mtr2	Frequency	0	0	960	Ramp
		control	3	50	960	Ramp
			6	100	960	Fixed

Tables VII VFD Input Data

ID	kVA	kV	FLA	Hz	% Imax	% PF
VFD 1	447	0.48	538	50	150	100

Tables VIII Auto-transformer Starting Device

Type	Motor	Switching	Values %	Unit	Ctrl Type
Auto-Xfmr	Mtr3	0 Sec.	85	%	Ramp
		4 Sec.	100		Fixed
		5 Sec.			Remove

After creating the research project as shown in Fig. 1, load flow analysis is run with Newton- Raphson method. This load flow analysis is shown in Fig. 2

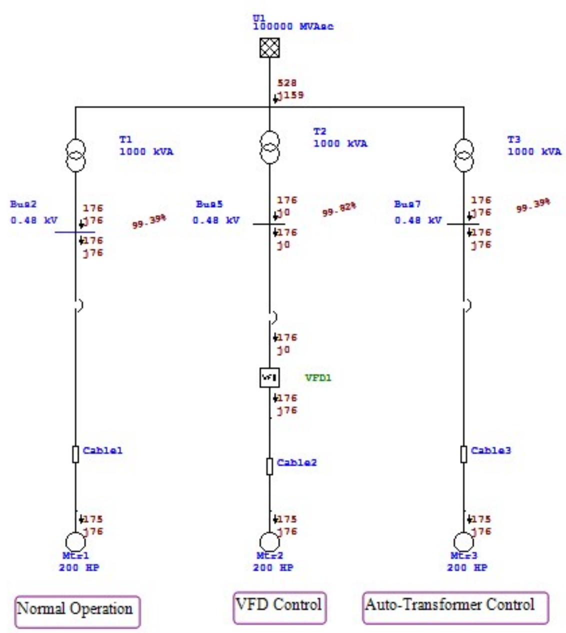
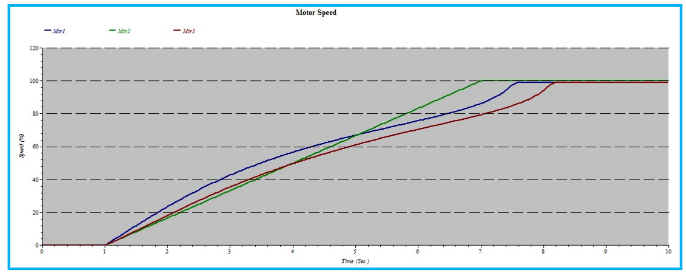


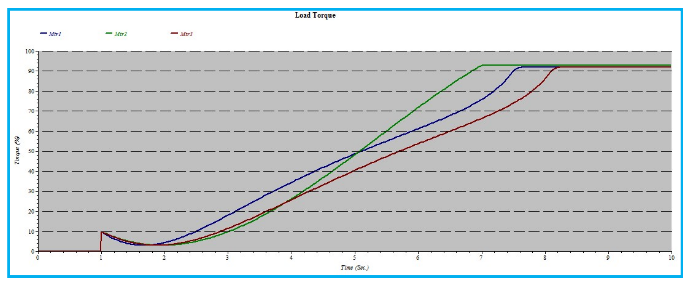
Fig. 2 Load flow analysis of test model

Fig. 3 (a) to (j) shows the comparison plot for dynamic motor acceleration analysis of three phase induction motor without starter, with VFD, and with auto-transformer on the same system.



(a) % of motor speed – time

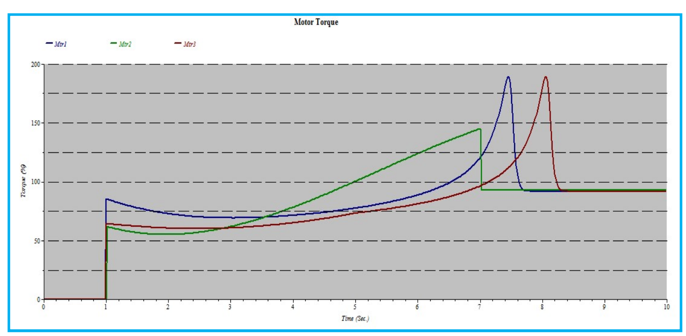
In Fig. 3 (a), the motor speed starts at 1 second with 0 % of rated speed for all motors, and rises to 100% of rated speed at 7 seconds with VFD, at 8.3 seconds with auto-transformer, and at 7.7 seconds without starter. By using variable frequency drive, the speed of motor 2 can be successfully started earlier than other two motors.



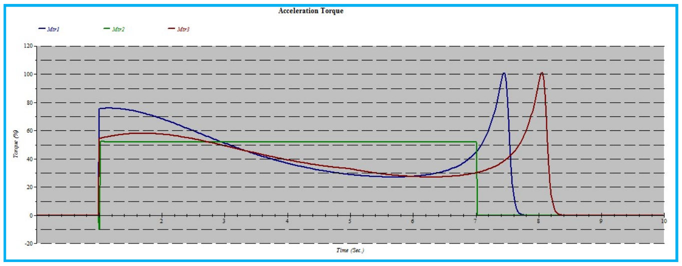
(b) % of load torque – time

In Fig. 3 (b), the load torque of all motors start at 1 second with 10 % of rated load torque. The load torque rises to 92% of rated load torque at 7 seconds for motor 2, at 8.3 seconds for motor 3, and at 7.7 seconds for motor 1. As a result, by using variable frequency drive, motor 2 can be achieved to steady state values of load torque within 7 seconds.

Fig. 3 (c) shows that all motors can provide the identical torque values (92% of rated load torque) at it's steady state time although the starting values of motor torque are different.

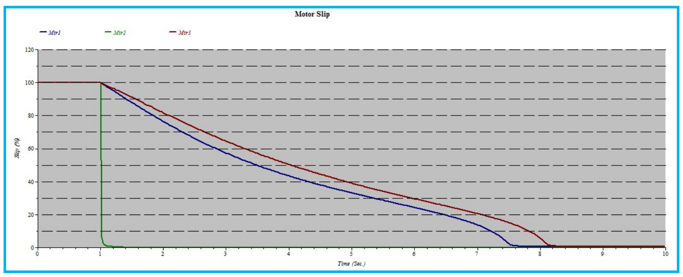


(c) % of motor torque – time



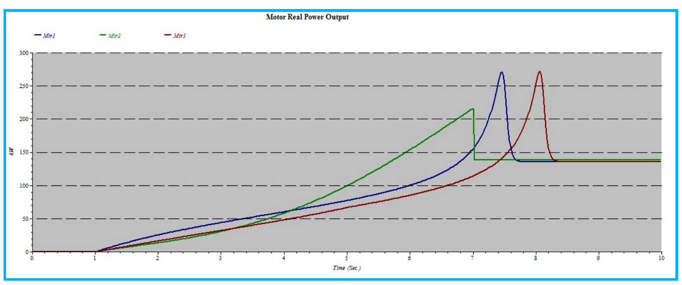
(d) % of acceleration torque – time

In Fig. 3 (d), the acceleration torque of motor 2 and motor 3 are less than motor 1 at starting time. However, all motor can operate with 92% of rated load torque because all motors are zero acceleration torque at their steady time.

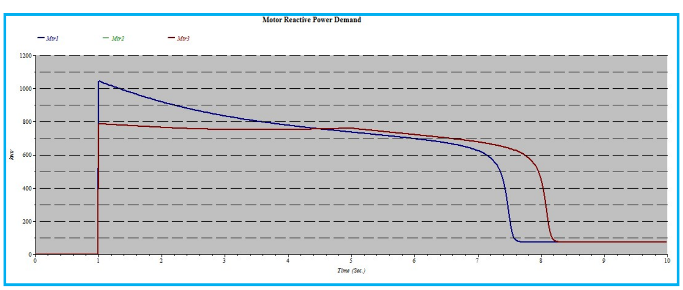


(e) % of motor slip – time

Fig. 3 (e) presents the slip of all motors are 100 % (S= 1) at starting time. And then the slip of each motors is arrived at 0 % (S=0). So, the induction machine is operating in motoring mode ($1 \geq S \geq 0$). The difference between the rotor speed and the synchronous speed of the rotating is called the slip.

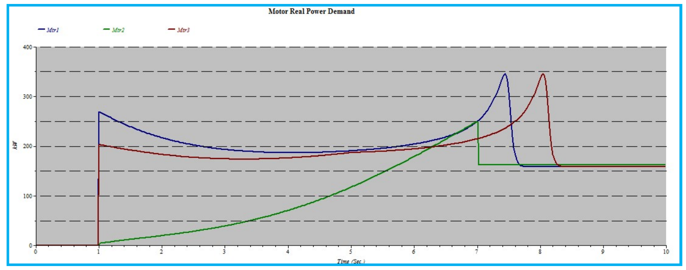


(f) Motor real power output – time



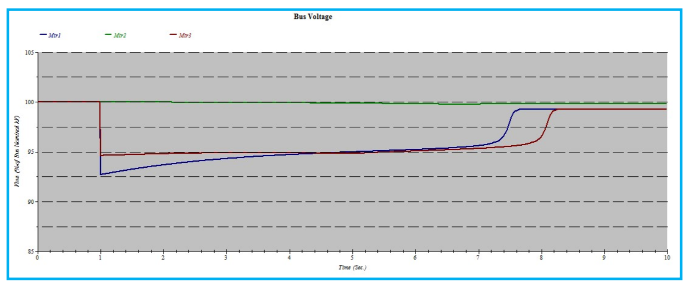
(g) Motor reactive power demand – time

According to Fig. 3 (f), (g) and (h), the real power consume of all motors at the steady state is the same. But, Fig. 3 (g) shows there is no reactive power demand for motor 2. Moreover, it can be seen that the reactive power demand for starting motor 3 is less than motor 1 (without starter). Therefore, the total energy of the system can be saved significantly at motor starting by using VFD, and auto-transformer.

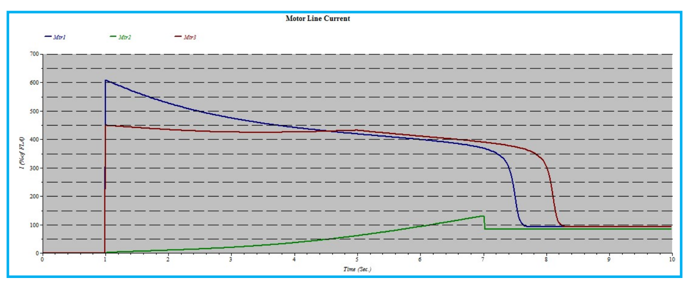


(h) Motor real power demand – time

In Fig. 3 (i), the bus voltage drop of motor 1 occurs 7.5 % of bus norminal voltage, however the bus voltage drop of motor 3 is 5% and the motor 2 is approximately 0.01 % of bus norminal voltage at starting time. It is show that the buses voltage of motor 2 and motor 3 can maintain at approximately 99.99 % and 95 % of bus norminal voltage (0.48 kV) at motor starting time (1 second).



(i) % of bus norminal voltage (bus 2,5,7) – time



(j) Motor line current – time

Fig. 3 Three phase induction motor's dynamic acceleration analysis

In Fig. 3 (j), the line current of motor 1 and motor 3 are 600 % & 450 % of FLC (full load current) at 1 second , and then the line current decrease until attaining a steady state values about 99.99 % of FLC. The line current of motor 2 is drawn 0 % of FLC at 1 second. The line current of motor 2 was increased gradually to reach about 140 % of FLC and then decreased immediately until achieving a steady state values about 99 % of FLC at 7 seconds. It can be seen that the line current of motor 2 and motor 3 can be reduced while starting time by the use of VFD and auto-transformer. As a consequence, the motor terminal voltage profile can be increased.

V. Conclusion

Generally, there are two important things to be considered in starting of three phase induction motors: (a) the starting current drawn from the supply line, and (b) the starting torque. The starting current should be kept small to avoid overheating of motor and excessive voltage drops in the system network. The starting torque must be regarding 50 to 100 % more than the expected load torque to ensure that the motor runs up in a reasonably short time.

In this paper, ETAP is employed to study motor acceleration analysis of three phase induction motor for a pump load. This motor starting analysis is described three conditions; normal operation, with VFD and with auto-transformer. Through this study, VFD and auto-transformer starter can provide a motor to be started successfully with a small current, the less voltage drop (can maintain bus voltage near rated voltage), a small torque and saving energy during the starting period. As can be seen from Fig. 3 (a- j), the starting motor with VFD method is better than auto-transformer starter.

References

[1]. DR. P. C. Sen, Principles of Electric Machines and Power Electronics, Third Edition, John Wiley & Sons. Inc., USA, 2014.
[2]. Velimir Lackovic, Char. Eng, Introduction to Motor Starting Analysis, Course No.E05-008
[3]. B. L. Theraja, A. K. Theraja, Electrical Technology, Multicolour Illustrative Edition , S. Chand. Ltd, 2005..
[4]. A. E. Fitzgerald, Charles Kingsley, Jr., Stephen D. Umans, Electric Machinery, Sixth Edition, Mc Graw Hill Companies, Inc, New York, 2003.
[5]. K. C. Agrawal, Electrical Power Engineering Reference& Applications Handbook, First Edition, ISBN:0-7506-7351-6, USA, 2007.
[6]. Technical document, ETAP Motor Acceleration Analysis, Operation Technology, Inc., 2009.