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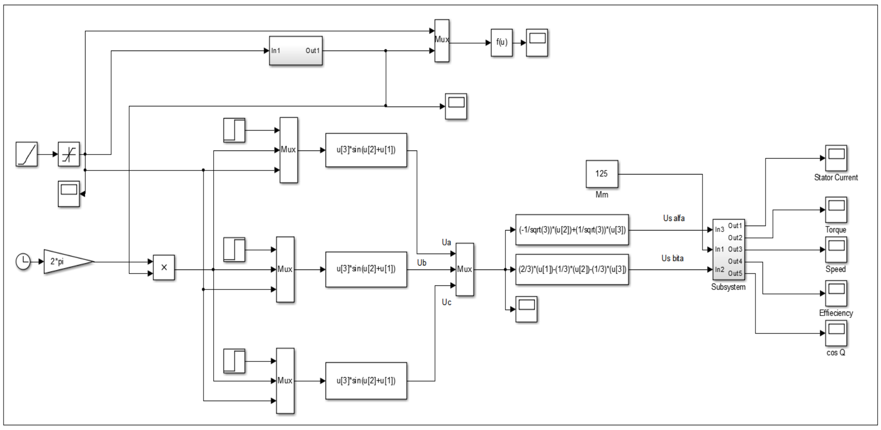
MASTER THESIS



Simulation of 3ph induction motor in Matlab with VVVF starting method

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Dissertation in Engineering Energy, 15 credits

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Abstract

Nowadays, three-phase induction motors are widely used on industrial and other types of processes. Therefore, accurate knowledge of an induction motor performance is very essential to have an idea of its operation conditions. This study is a sequel of a previous one, where Direct and Soft starting methods of three-phase motors has been simulated and compared. As in the previous study, the theory behind this one is based on representing the real motor by a set of equations and values in Matlab, forming a corresponding idealistic motor in a way where all the physical effects are similar. The motor is started under three different frequencies in the VVVF method using supporting simulation of the current, torque, speed, efficiency and power factor curves. The results of the three starting methods are then discussed and compared.

Keywords: 3ph-induction motor, Matlab, Model, Simulation, VVVF starting, Direct starting, Soft starting.

Sammanfatning

Numera är tre-fas asynkronmotorer i stor utsträckning på industriella och andra typer av processer. Därför är det mycket viktigt att ha exakt kunskap om en induktionsmotorprestanda för att ha en uppfattning om dess driftsförhållanden . Denna studie är en fortsättning av en tidigare, där direkt och mjukstart metoder för trefasmotorer har simulerats och jämförts. Såsom i den tidigare studien, är teorin bakom denna en baserat på representerar den verkliga motorn av en uppsättning ekvationer och värden i Matlab, som bildar en motsvarande ideell motor på ett sätt där alla de fysiska effekterna är likartade . Motorn startas under tre olika frekvenser i VVVF metod med stöd simulering av ström, vridmoment, hastighet, effektivitet och effektfaktorn kurvor. Därefter, resultaten av de tre startmetoder diskuteras och jämföras.

Nyckelord: 3-fas-induktionsmotor , Matlab, modell, simulering, VVVF start, direktstart , mjukstart.

ملخص

في الوقت الحالي تستخدم المحركات التحريضية ثلاثية الطور بشكل واسع في التطبيقات الصناعية و غيرها. و لهذا فإن المعرفة الدقيقة بأداء المحرك التحريضي أساسية لإعطاء فكرة عن ظرف تشغيله. إن هذه الدراسة هي تتمة لدراسة سابقة حيث تمت محاكاة و مقارنة طريقتي الإقلاع المباشر و الناعم للمحرك التحريضي ثلاثي الطور. كما في الدراسة السابقة, فإن هذه الدراسة مبنية على تمثيل المحرك الحقيقي بمجموعة من المعادلات و القيم الاسمية في برنامج ماتلاب لتكوين محرك مثالي مطابق, بحيث تكون جميع الآثار الفيزيائية مماثلة للمحرك الحقيقي. يتم إقلاع المحرك عند ثلاث ترددات مختلفة بطريقة تغيير التردد و التوتر و يتم محاكاة هذا الإقلاع عبر منحنيات التيار، العزم، السرعة، المردود و عامل الاستطاعة ثم تقارن نتائج طرق الإقلاع الثلاثة.

الكلمات المفتاحية: المحرك التحريضي ثلاقي الطور, ماتلاب, نموذج, محاكاة, الإقلاع بتغيير التوتر و التردد, الإقلاع المباشر, الإقلاع الناعم .

Acknowledgement

I am grateful to God for the support, good health and wellbeing that were necessary to complete this project. I feel deeply honored expressing my sincere thanks to docent Jonny Hylander for providing valuable insights leading to the successful completion of my thesis. I take this opportunity to express gratitude to all of the department faculty members for their help and support. I also thank my loving family and friends for the encouragement, support and attention through this venture.

Glossary of Symbols

i_{α}^{s} : The stator current represented on the axis alpha.

i_{β}^{s} : The stator current represented on the axis beta.

i_{α}^{r} : The rotor current represented on the axis alpha.

i_{β}^{r} : The rotor current represented on the axis beta.

u_{α}^{s} : The stator voltage represented on the axis alpha.

u_{β}^{s} : The stator voltage represented on the axis beta.

u_{α}^{r} : The rotor voltage represented on the axis alpha.

u_{β}^{r} : The rotor voltage represented on the axis beta.

M (or Lm): the mutual inductance.

Rr: the rotor resistance.

Ls: the stator inductance.

Lr: the rotor inductance.

Rs: ohm the stator resistance.

P: the number of pairs of poles.

J: the moment of inertia.

Wrb (or Wr): the angular velocity.

Tb: the nominal torque.

Ib: the nominal current.

nb: the motor speed.

η : the efficiency.

p2(t): the mechanical power (output of the motor).

p1(t): the electrical power (input of the motor).

$\cos\varphi_1$: the power factor.

Tem: the electromagnetic torque.

Pn: real power in kW.

p_{α}^{s} : The stator real power represented on the axis alpha.

p_{β}^{s} : The stator real power represented on the axis beta.

q: reactive power.

q_{α}^{s} : The stator reactive power represented on the axis alpha.

q_{β}^{s} : The stator reactive power represented on the axis beta.

S: apparent power.

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1 Background

1.1 Introduction

Nowadays three-phase induction motors are widely used on industrial process, pumping, agriculture, and mining applications, due to their high efficiency, robustness, low maintenance and low cost [1]. The U.S. Department of Energy estimates that electric motors consume 63% of all electricity used in industry [8]. The most important phase in the motor is the starting, where the motor properties play a major role in the evaluation of all electrical motors, and these properties are defined by factors such as starting torque, starting current, transient state, smoothness of the starting and simplicity and economics of starting [2]. Therefore, many simulations of the three-phase induction machine are well documented in the literature including the starting phase, and digital computer solution can be performed using various methods [3].

Accurate knowledge of an induction motor performance is very essential to have an idea of its operation conditions. Computer simulation plays an important role in engineering course teaching. Nowadays, a variety of software tools are available to simulate electrical circuits, one of them is MATLAB [4]. Matlab/Simulink is a systems simulator and unable to direct simulate electrical circuits. Therefore for simulation of electric circuits power system block set is used, which is incorporates libraries of electrical blocks and analysis tools which are used to convert electrical circuits into Simulink diagrams [5]

The majority of the induction motor faults make their presence unexpectedly during operation. So, one may conclude about the main characteristics a diagnostic method should have, in order to be applied in real operating systems [6]. Induction motors condition monitoring is a very important process for immediate detection of the incipient faults. This prevents the spread of the faults up to risky degrees and avoids catastrophic stop of the motor and relevant production line. Condition monitoring is important to maintain sustained operability of machinery. The ability to effectively and efficiently monitor the condition of industrial machines allows the user to have a clear understanding of any problems that may arise during machine operation. Condition monitoring has the clear advantage of offering the ability to perform just-in-time maintenance i.e. before failure occurs but only as necessary. This aspect allows companies to reduce downtime when repairing machinery and ensures that productivity does not suffer [7]. Expert Systems use measurement data and knowledge base to point out and explain reasons of fault. This approach is very effective if one knows all possibilities of faults [9].

In order to simplify the analysis of three phase circuit, Direct Quadrature (d-q) transformation is used as mathematical transformation . In the case of balanced three phase circuits, application of d-q transformation reduces the three AC quantities to two quantities. Simplified calculations can then be carried out on these imaginary quantities before performing the inverse transformation to recover the actual three phase ac results [10].

1.2 The general theory of electrical machines:

This theory is based on representing the real machine with a corresponding idealistic machine in a way where all the physical effects are similar. This idealistic machine is symmetrical (has two poles and two phases) and has two pairs of identical windings on perpendicular axes in both of the stator and the rotor. The windings are fed by two AC currents that are shifted by

(90°) from each other according to time as shown in figure (1.1). The idealistic machine is treated as a two poles machine because the magnetic flux distribution is repeated after each pair of poles, no matter how many poles there are in the real machine [2].

In the idealistic machine, the electrical and the geometrical axes are Identical. This property simplifies detecting the rotor's position with reference to the stator during transient state. This transient state has a very complicated physical effect, which makes it almost impossible to mathematically study the machine without applying some theories and assumptions. The complexity is caused by the nonlinearity of the magnetization curve and the elements of the machine, and their dependence to the currents passing through the windings. Another factor of the complexity is the non-sinusoidal curve of the windings electromagnetic force which alters according to the working system of the machine.

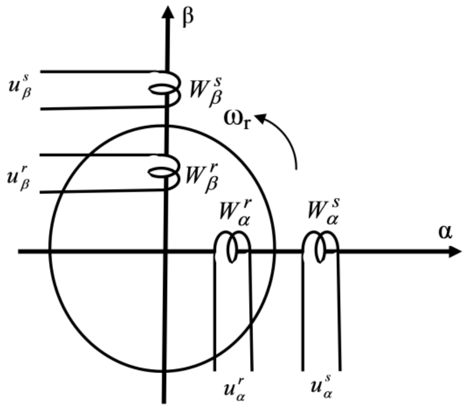


Figure (1.1) the ideal machine circuit

Considering the previous obstacles, it is found that the mathematical study would lead to nonlinear equations that are non-analyzable. Therefore, the basic factors are approximated whereas subsidiary factors are totally neglected. Applying these steps would lead to an analyzable idealistic machine which has the following specifications [2]:

- The air-gap is steady.
- The winding are distributed on the circumference of the rotor and the stator in a way that ensures a steady distribution for the current and a sinusoidal distribution for the electromotive force.
- The magnetic circuit is unsaturated.
- The absolute resemblance between the stator and the rotor windings.
- The windings leakage flux is independent from the rotor location.
- The reluctance of the stator and rotor should be neglected

In all electrical machines, studies in [11, p 21] show that the magnetic fields in both of the rotor and the stator are static with respect to each other. Furthermore, this is a crucial condition of power conversion.

When running electrical machines, a few phenomena occur and it is required to represent these phenomena as mathematical equations in order to study the machine. These equations depend on each other, but one can any way consider them to belong to one of three groups which describe [11, p 22]:

- The windings voltages.
- The torques on the axis of the machine.
- The mechanical motion.

In order for these equations to be written in a standard way, it is important to consider the following [11, p 23]:

- The positive direction of the current passing through the windings is from the windings ending towards its beginning.
- The electromotive force has the same positive direction as the current.
- The positive direction of the magnetic flux is the direction of the flux coming out of the rotor.
- The positive direction of the winding axes and the electromagnetic force is the same positive direction of the current.
- The positive direction of the machine revolution, the electromotive force and the angles calculation is counter clockwise.

1.3 Problem formulation

This study is a sequel of a previous one, where two methods of starting three-phase motors has been simulated and compared through curves of currents, torque, speed, efficiency and power factor. These methods are Direct and Soft starting. In this study, three cases of different frequencies of the VVVF (which is short for "variable voltage variable frequency") starting method will be simulated and discussed in a similar manner. The investigation will be based on a Matlab simulation of different frequency cases of the induction motor. The induction motor model is created according to a group of standard equations and values developed and edited using a computer [2].

2 Aim

The aim of this study is to simulate the starting process of a specific three phase induction motor in the VVVF method under three frequencies, to have a better evaluation of the motor's performance. The results will be compared with Direct and Soft starting and conclusions will be made.

3 Method

3.1 Simulation preparations

A simulation will be conducted on a mathematical model of a three phase induction motor by starting it in VVVF. The motor will be described by a set of equations and its nominal values in order to simulate it in Matlab. With the equations, it is possible to calculate the current, the torque, the input and the output power, the efficiency, and the power factor. The equations are used along with the nominal values to make a block which represents the motor in Matlab.

In order to study the mathematical model of the motor, several equations system should be used. One of the preferred systems is the (alpha, beta) system which is fixed on the stator. This will be done with the help of (d,q) system by a simple conversion between these systems.

Comparing the states of the motor is possible using the subsystem feature in Matlab figure (3.1). This feature requires building another block which contains the previous one and controls its inputs and outputs as in figure (3.2). In other words, the motor is the subsystem shown in figure (3.2) which can be controlled by the main system shown in figure (3.1). After building the previous blocks, each of the starting methods is simulated individually.

3.2 Simulating and starting the motor in Matlab

3.2.1 The induction motor model:

In order to simulate the 3ph induction motor in Matlab, the motor is represented by a set of equations and values according to the following steps:

3.2.1.1 The motor equations on the coordinates system ($\alpha - \beta$) are set as:

In this study, the motor will be represented by five sets of equations, which are: the currents, the torque, the speed, the input and output power, the efficiency and the power factor.

3.2.1.1.1 Currents equations [2] or [13, p 45]

$$\frac{di_\alpha^s}{dt} = \frac{1}{L_s} u_\alpha^s - \frac{R_s}{L_s} i_\alpha^s - \frac{M}{L_s} \frac{di_\alpha^r}{dt} \qquad \text{eq.(1)}$$

$$\frac{di_\beta^s}{dt} = \frac{1}{L_s} u_\beta^s - \frac{R_s}{L_s} i_\beta^s - \frac{M}{L_s} \frac{di_\beta^r}{dt} \qquad \text{eq.(2)}$$

$$\frac{di_\alpha^r}{dt} = -\frac{R_r}{L_r} i_\alpha^r - \frac{M}{L_r} \frac{di_\alpha^s}{dt} - \omega_r i_\beta^r - \omega_r \frac{M}{L_r} i_\beta^s \qquad \text{eq.(3)}$$

$$\frac{di_\beta^r}{dt} = -\frac{R_r}{L_r} i_\beta^r - \frac{M}{L_r} \frac{di_\beta^s}{dt} + \omega_r i_\alpha^r + \omega_r \frac{M}{L_r} i_\alpha^s \qquad \text{eq.(4)}$$

3.2.1.1.2 Torque and speed equations [2] or [12, p18]:

$$T_{em} = \frac{3}{2} PM (i_\beta^s i_\alpha^r - i_\alpha^s i_\beta^r) \qquad \text{eq.(5)}$$

$$\frac{d\omega_r}{dt} = \frac{P}{J} (T_{em} - T_m) \qquad \text{eq.(6)}$$

3.2.1.1.3 Input and output power equations [2]:

$$p_s(t) = p_\alpha^s + p_\beta^s = 3/2(u_\alpha^s i_\alpha^s + u_\beta^s i_\beta^s) \qquad \text{eq.(7)}$$

$$q_s(t) = q_\alpha^s + q_\beta^s = 3/2(u_\beta^s i_\alpha^s - u_\alpha^s i_\beta^s) \qquad \text{eq.(8)}$$

$$s(t) = \sqrt{p_s{}^2 + q_s{}^2} \qquad \text{eq.(9)}$$

$$p_2(t) = T_{em}.\Omega_r = T_{em}.\frac{\omega_r}{P} \qquad \text{eq.(10)}$$

3.2.1.1.4 Efficiency and power factor equations [2]:

$$\eta = \frac{p_2(t)}{p_1(t)} \qquad \text{eq.(11)}$$

$$\cos\varphi_1 = \frac{p_1(t)}{s(t)} \qquad \text{eq.(12)}$$

3.2.1.2 On the other hand, the currents passing through the phases of the induction motor are given by [2]:

$$i_A^s = i_\alpha^s \qquad \text{eq.(13)}$$

$$i_B^s = -\frac{1}{2} i_\alpha^s + \frac{\sqrt{3}}{2} i_\beta^s \qquad \text{eq.(14)}$$

$$i_C^s = -\frac{1}{2} i_\alpha^s - \frac{\sqrt{3}}{2} i_\beta^s \qquad \text{eq.(15)}$$

3.2.1.3 The equations will be represented and simulated as a block diagram shown in figure (3.1).

The model and the code are built according to the following values which were experimentally chosen. The model is a combination of standard models that were implemented according to standard equations [2]. This process is quite complicated and can not be explained in this report:

$P_n = 18.5\,kW$	$R_s = 0.159\,\Omega$	$M = 0.0489\ H$
$2P = 4\ \ poles$	$R_r = 0.16\,\Omega$	$J = 0.234\,kg.m^2$
$U_n = 220\ V$	$L_s = 0.05\,H$	$I_b = 52\,A$
$n_b = 1500\,r.p.m$	$L_r = 0.051\,H$	$T_b = 125\,N.m$
$\omega_{rb} = 314\,rad/\sec$	$f = 50\,Hz$	

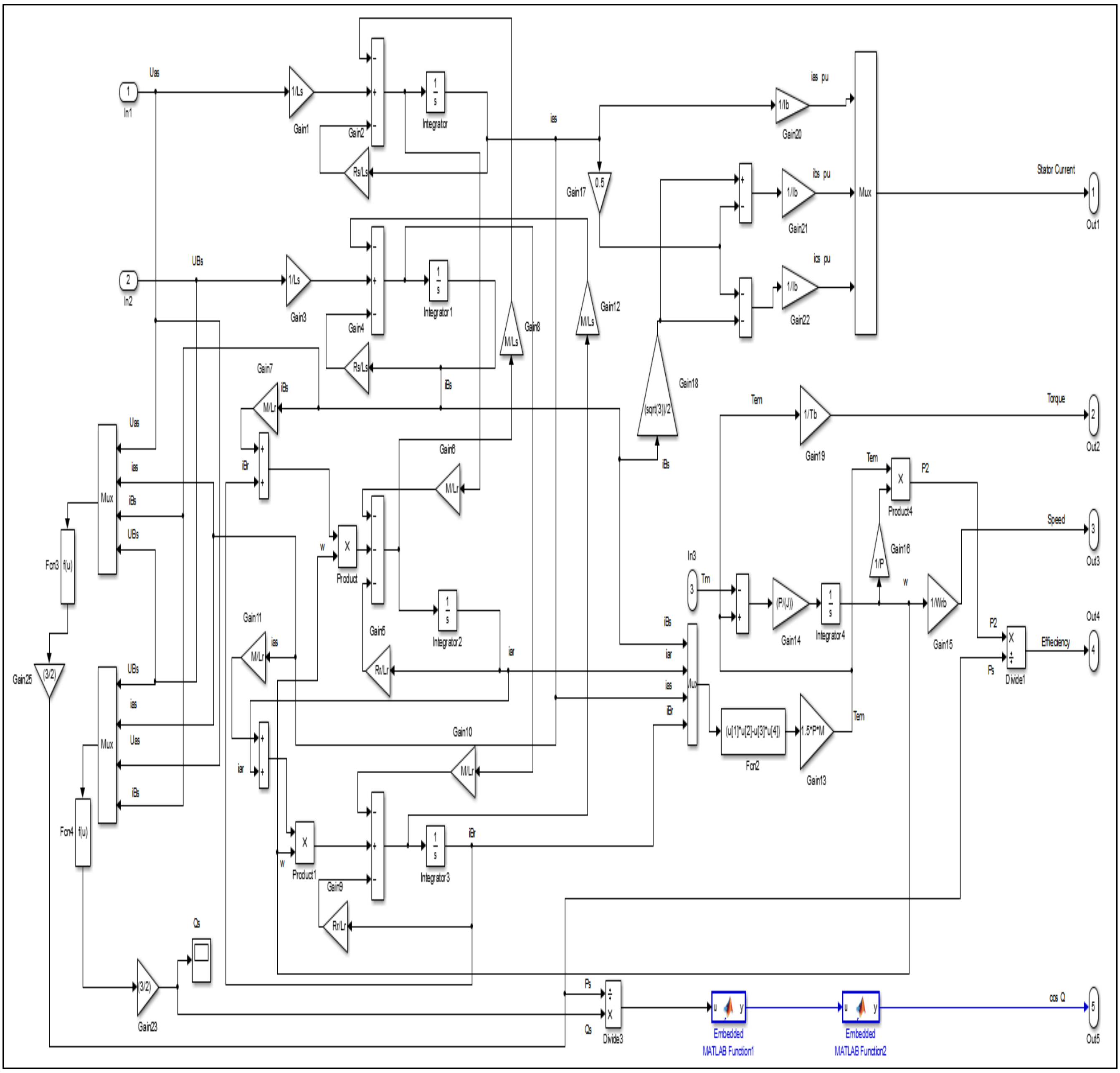


Figure (3.1) Block diagram (1) for the induction motor model in Matlab as a subsystem

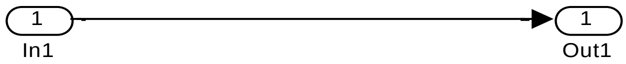
3.2.2 Creating the subsystem:

To be able to compare the states of the motor with each other, a new block diagram -based on the previous one- is made. This new block shown in figure (3.2) is built in Matlab using the subsystem method as explained in the following steps:

A new model is opened from:

File → New → Model

- From the library browser, the option (ports & subsystem) is taken.
- The (subsystem) icon is dragged into the opened model and then double-clicked.
- The following icons -which represent the subsystem content-, would appear.



- The line between in1 and out1 is deleted.
- The number of inputs and output is determined applying the (copy& paste) feature.
- The induction motor model is pasted into the subsystem page, excluding the inputs and the outputs.
- The outputs of the (subsystem) are set to be the following: (Currents, Torque, Speed, Efficiency, Power factor), where every output is connected to a (scope).

3.3 The starting method VVVF simulation

In this method, both of the voltage and the frequency applied on the motor are raised, starting from a certain value up to the nominal values on page (14) (v = 220, f = 50) as shown in figure 3.2. It is essential to keep the ratio $\frac{\mathrm{V}}{\mathrm{f}} = constant$ to maintain a steady $T_{\max}$ for the motor and this depends on the magnetic flux in the machine. In other words, with a constant flux (no saturation) the $\frac{\mathrm{V}}{\mathrm{f}}$ quotient is constant, whereas with resistive voltage drop in the machine, the quotient must increase with increasing load. Obviously, it is not possible to change the grid frequency meaning that we need an external power source with an alternating frequency, but this step can be easily done in Matlab using a few blocks which represent the frequency converter as in figure (3.2).

3.3.1 Frequency converter losses

The frequency converter losses are and not determined easily, since they are not all constant, but consist of a constant part and a load dependent part. The constant losses are like losses in the electronic circuits or cooling losses, whereas the load dependent losses comes from the power semiconductors as lead losses or can be switching losses. Since these losses are physical losses, they will not be an obstacle in this simulating study.

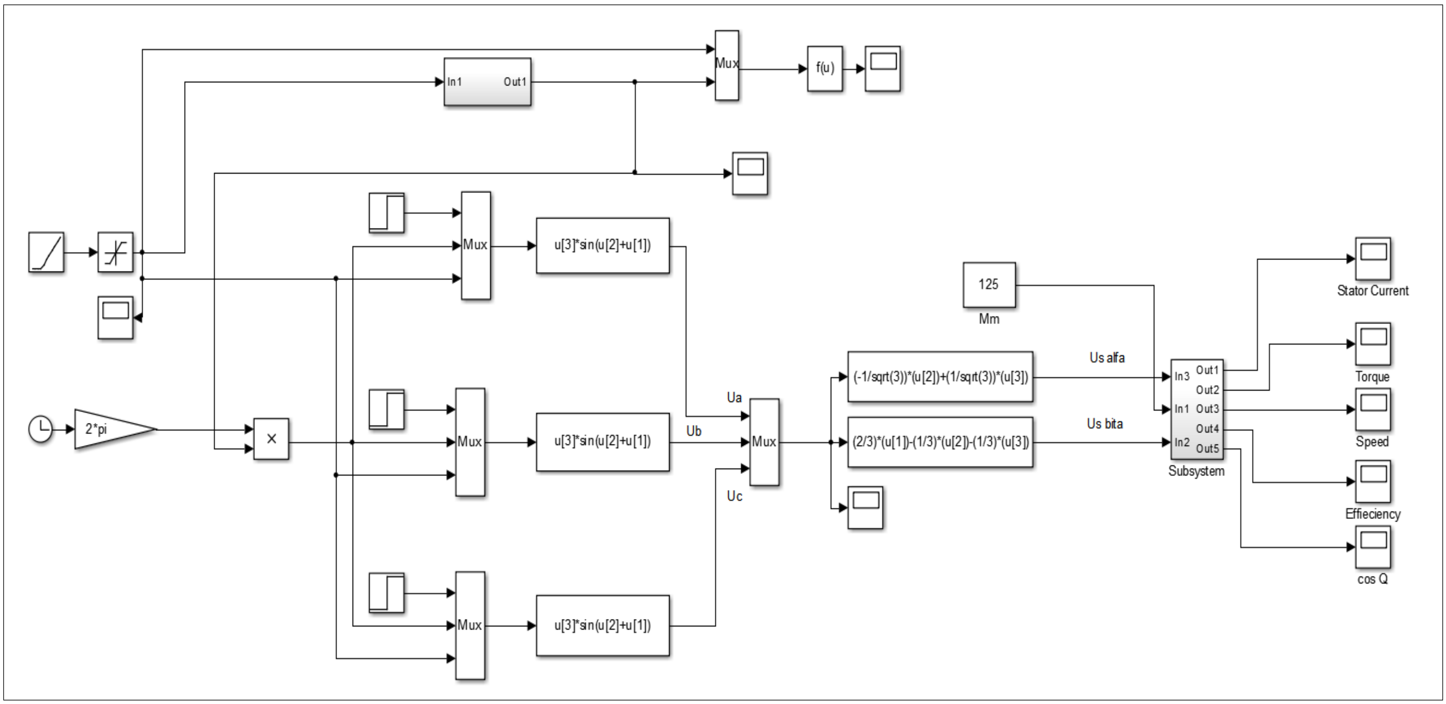


Figure (3.2) Block diagram (2) for the induction motor model in Matlab as the main system

The following cases of the frequency, which were chosen randomly, will be simulated:

$$f = 17Hz$$

$$f = 23Hz$$

$$f = 35Hz$$

3.3.2 Simulating f = 17 Hz

In this case the starting frequency will be set to be 17 Hz and will be raised to meet the nominal value.

Note: in all the following simulations, the horizontal axis represents the time by seconds, while the vertical is per unit.

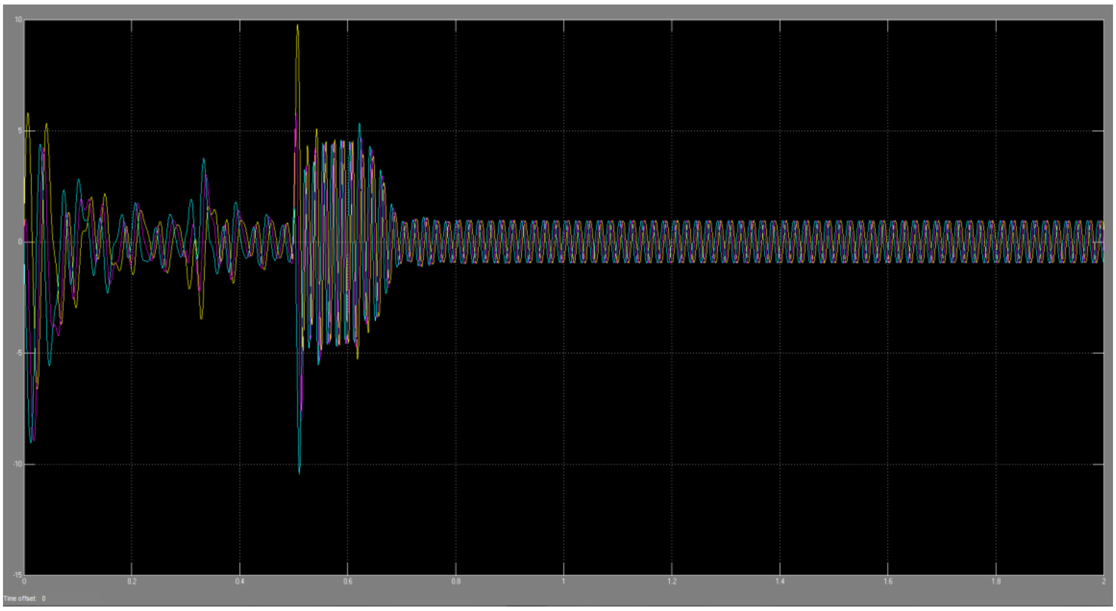


Figure (3.3) Starting currents curves in the f = 17 Hz case.

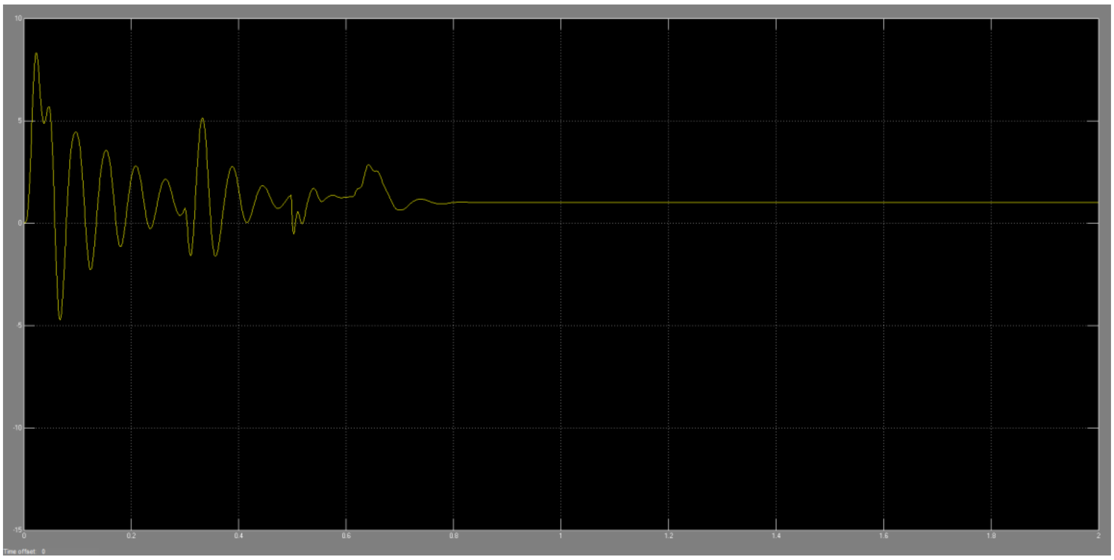


Figure (3.4) Starting torque curve in the f = 17 Hz case.

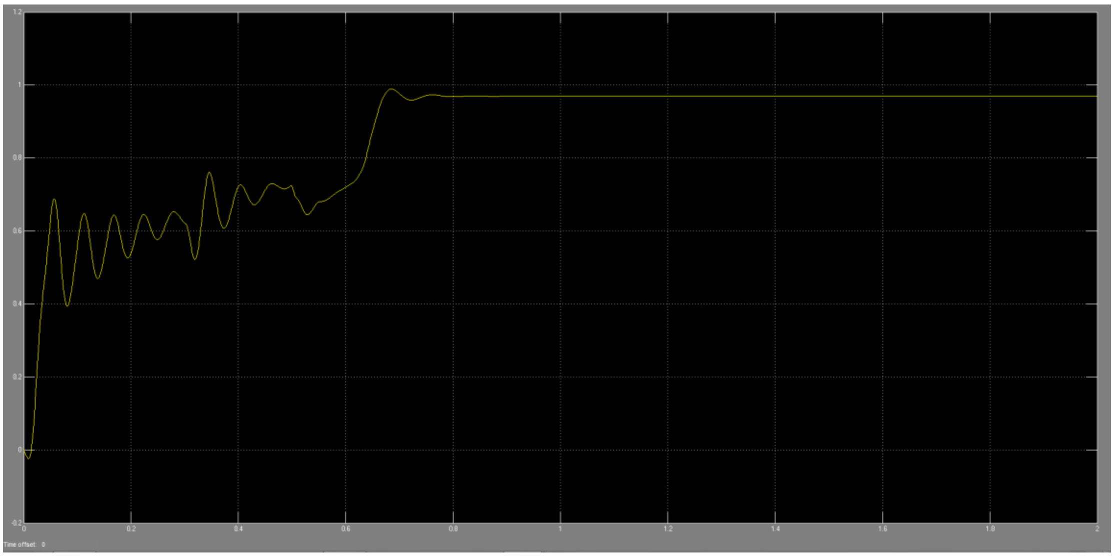


Figure (3.5) Starting speed curve in the f = 17 Hz case

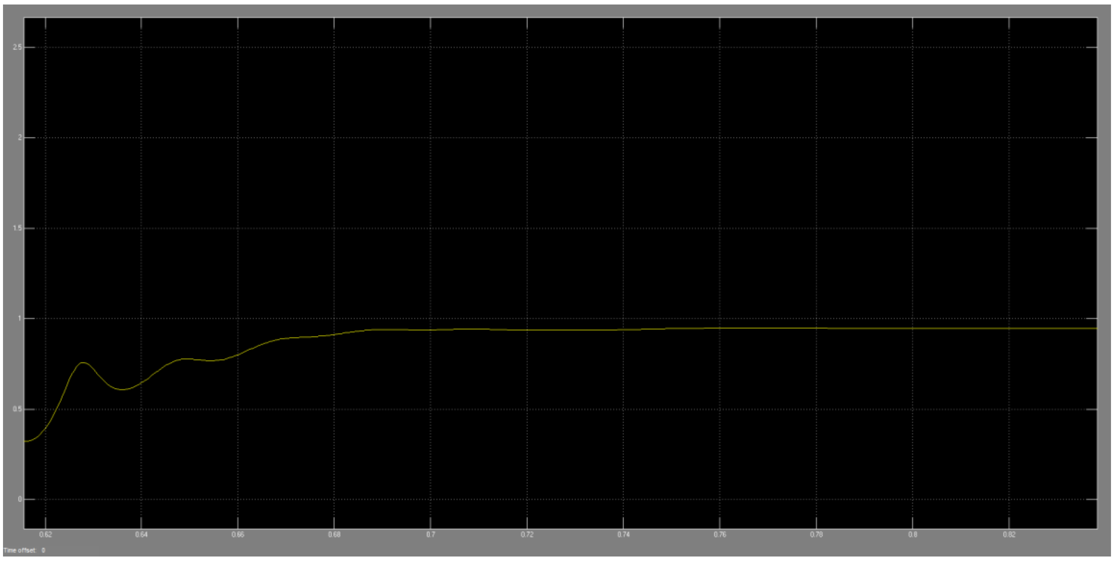


Figure (3.6) Efficiency curve in the f = 17 Hz case.

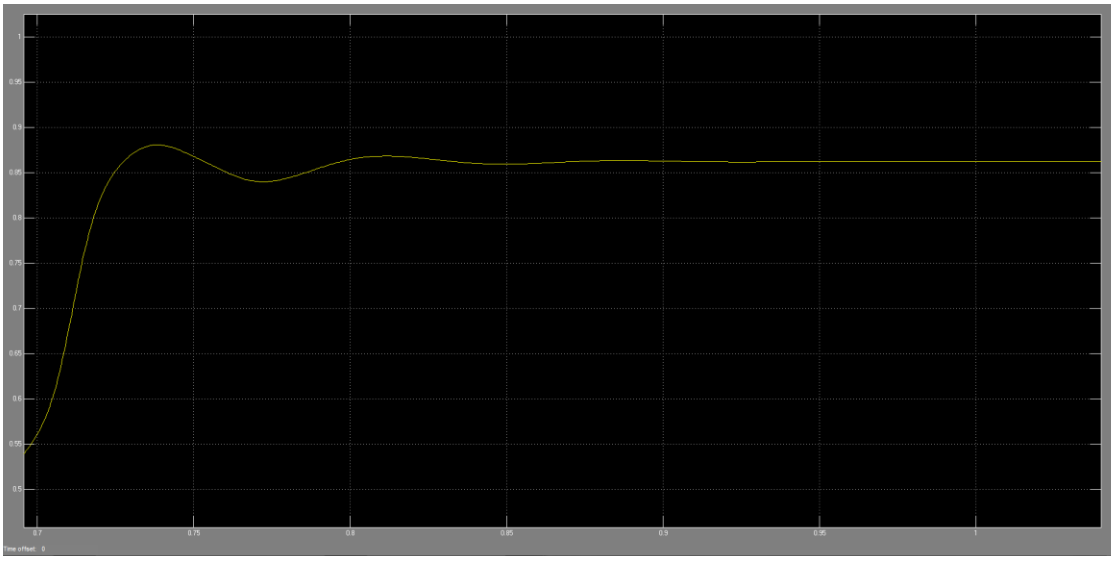


Figure (3.7) Power factor curve in the f = 17 Hz case

Table (3.1) shows the values of the starting current, the starting torque, the transient state period, the efficiency and the power factor in the f = 17 Hz case. For example, the value of the starting current is the largest value at the positive pulse, and so is the value of the starting torque. All of the previous variables values are obtained during the transient state, which is the time needed to reach stationarity, except for the efficiency and the power factor, which are taken after. Stationarity is reached when the speed curve reaches a certain value and gets steady. For example, in figure (3.5) the speed reaches stationarity at about (0.82).

Table (3.1) results at the f = 17 Hz case

Ist (pu)	Tst (pu)	Transient (s)	Efficiency (%)	Power factor (%)
9.8	8.3	0.82	95	86

3.3.3 Simulating f = 23 Hz

In this case the staring frequency will be set to be 23 Hz and will be raised to meet the nominal value.

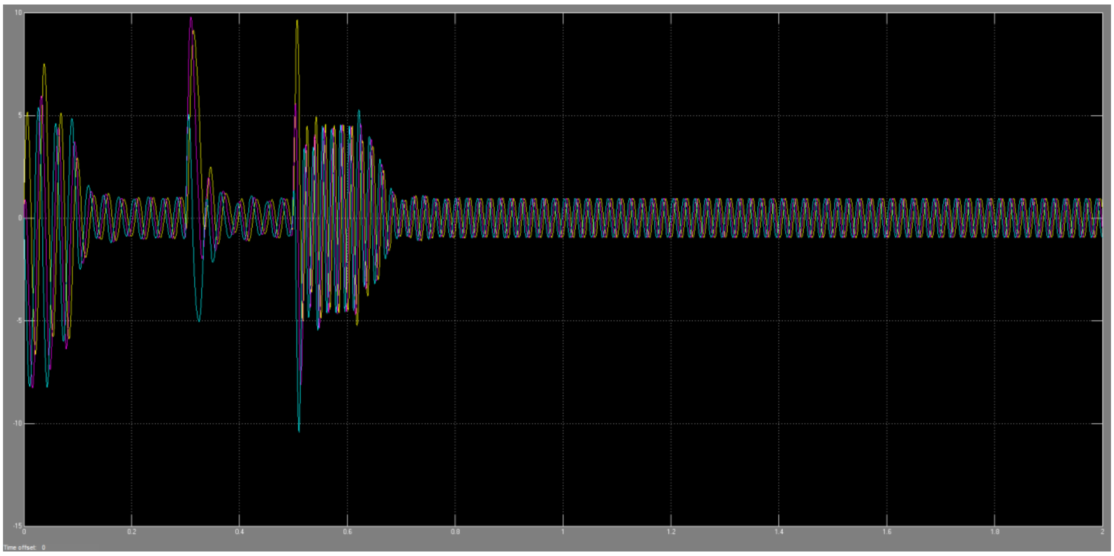


Figure (3.8) Starting currents curves in the f = 23 Hz case.

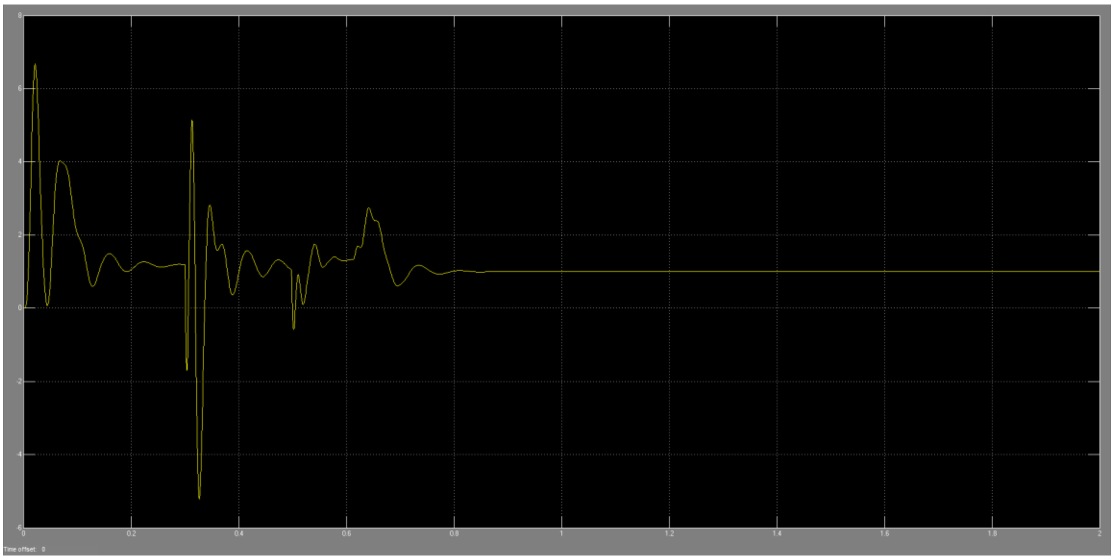


Figure (3.9) Starting torque curve in the f = 23 Hz case.

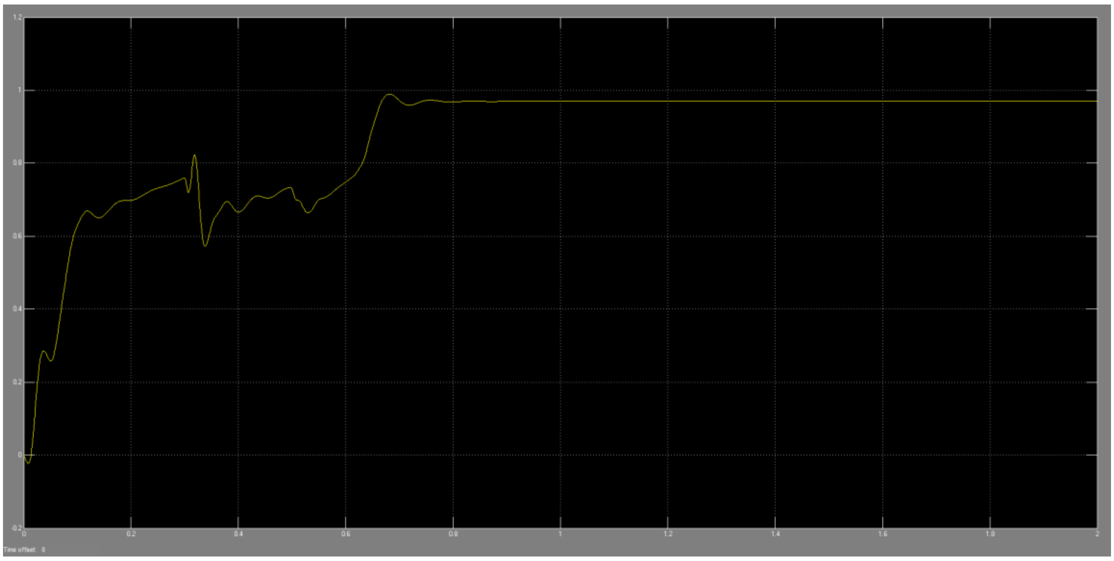


Figure (3.10) Starting speed curve in the f = 23 Hz case

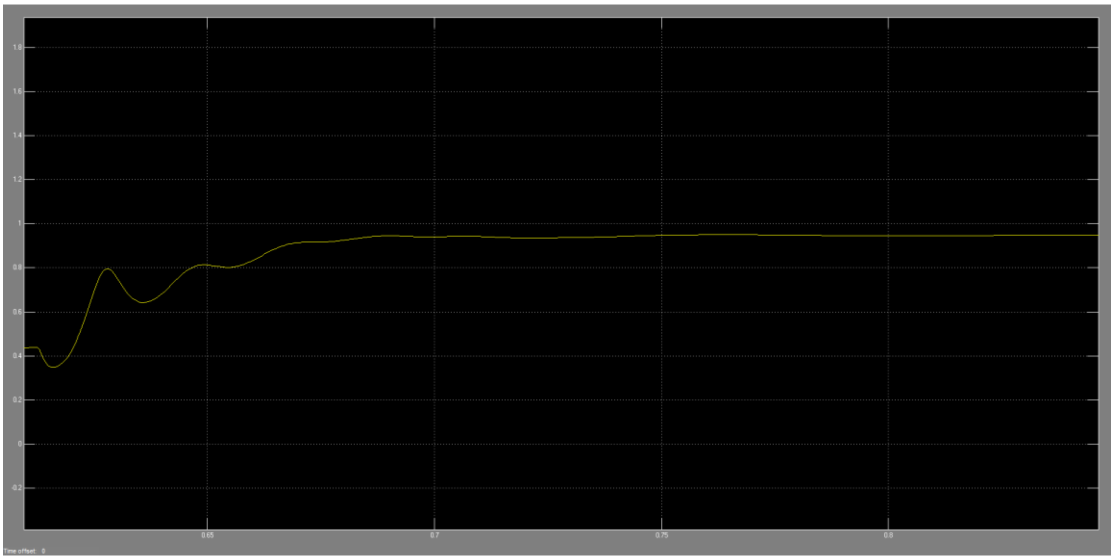


Figure (3.11) Efficiency curve in the f = 23 Hz case.

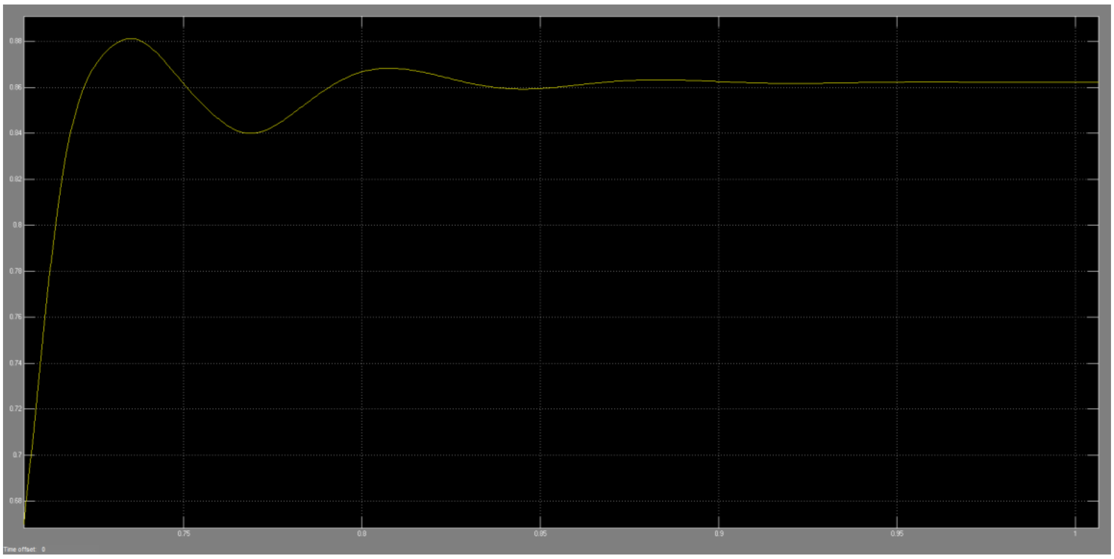


Figure (3.12) Power factor curve in the f = 23 Hz case

Table (3.2) shows the values of the starting current, the starting torque, the transient state period, the efficiency and the power factor in the f = 23 Hz case.

Table (3.2) results at the f = 23 Hz case

Ist (pu)	Tst (pu)	Transient (s)	Efficiency (%)	Power factor (%)
9.7	6.7	0.83	95	86

3.3.4 Simulating f = 35 Hz

In this case the staring frequency will be set to be 35 Hz and will be raised to meet the nominal value.

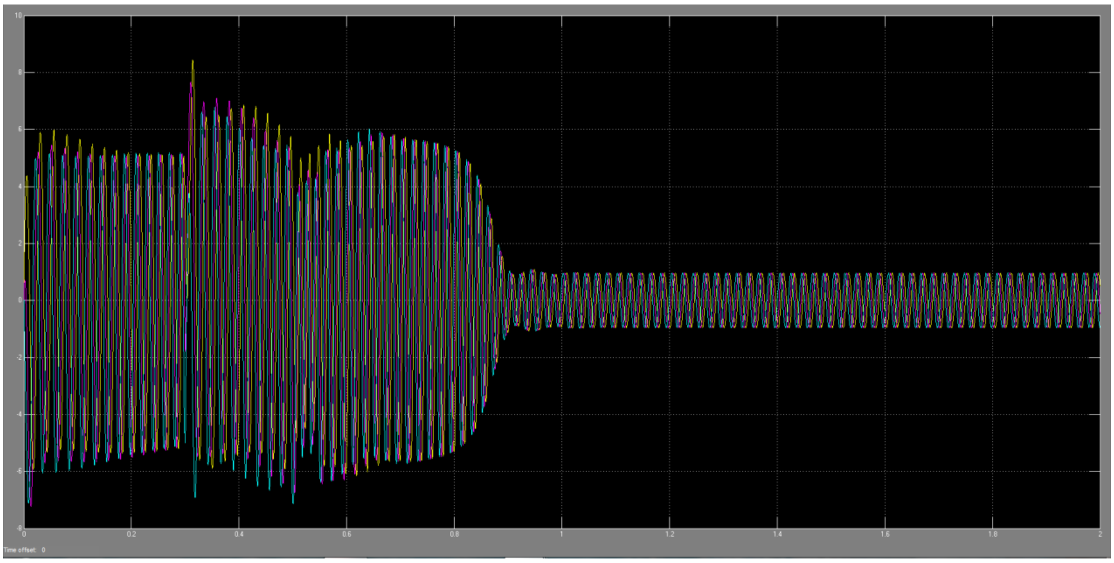


Figure (3.13) Starting currents curves in the f = 35 Hz case.

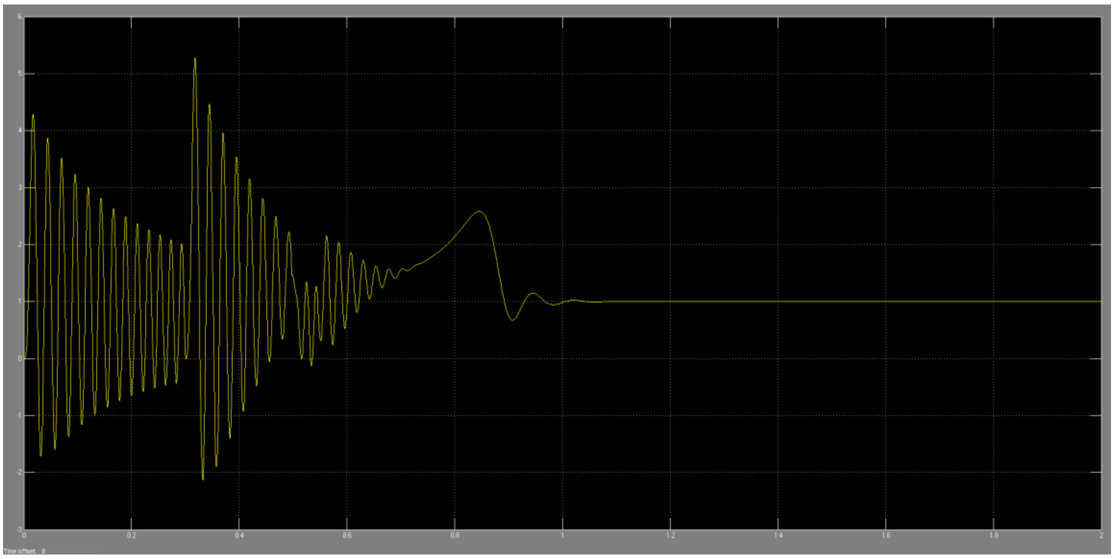


Figure (3.14) Starting torque curve in the f = 35 Hz case.

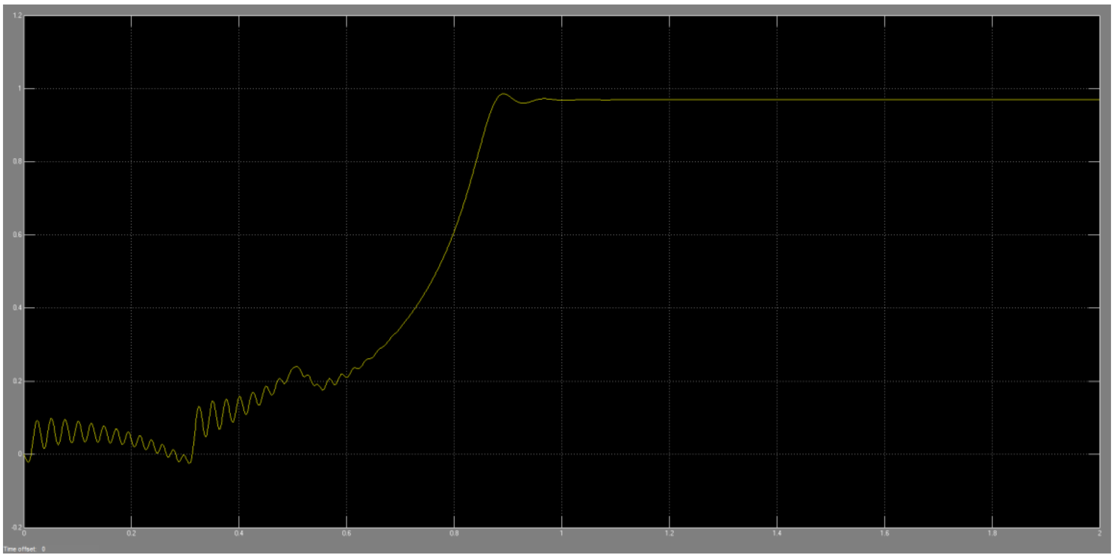


Figure (3.15) Starting speed curve in the f = 35 Hz case

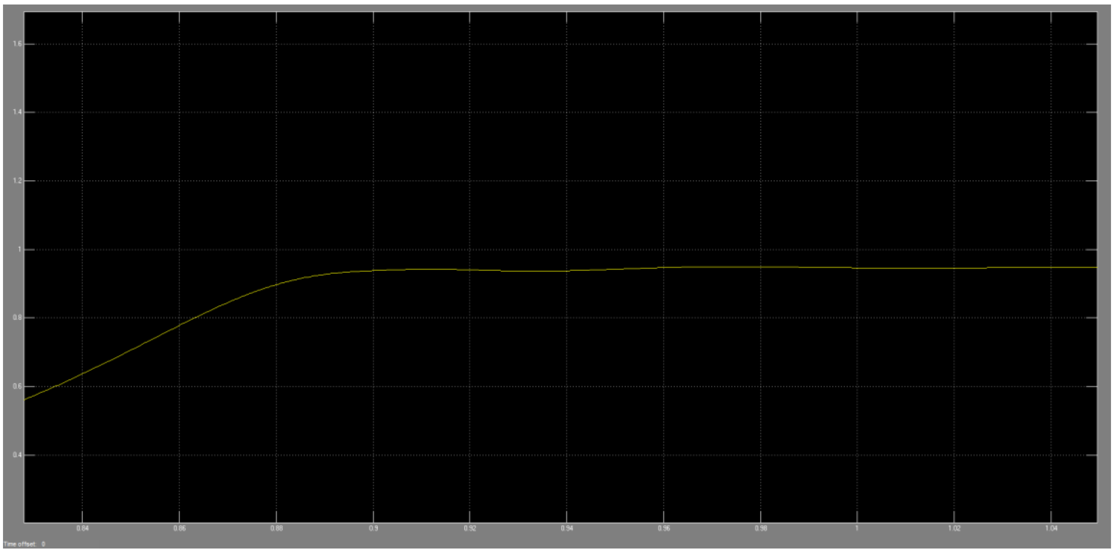


Figure (3.16) Efficiency curve in the f = 35 Hz case.

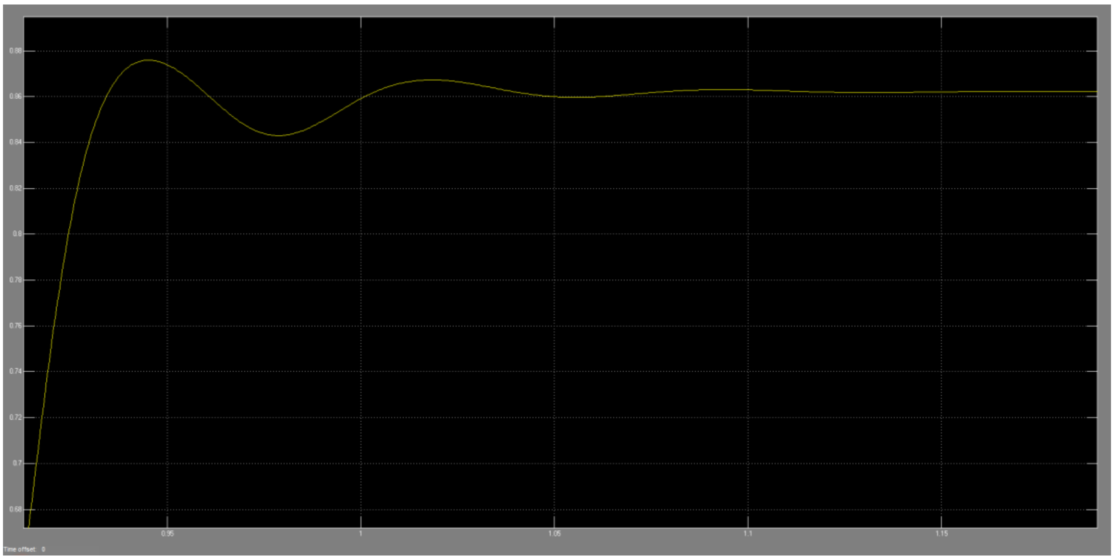


Figure (3.17) Power factor curve in the f = 35 Hz case

Table (3.3) shows the values of the starting current, the starting torque, the transient state period, the efficiency and the power factor in the f = 35 Hz case.

Table (3.3) results at the f = 35 Hz case

Ist (pu)	Tst (pu)	Transient (s)	Efficiency (%)	Power factor (%)
8.4	5.3	1	95	86

4 Discussion and conclusions

4.1 VVVF results

In this chapter, the results of the different frequency cases in the VVVF method are highlighted and discussed according to the previous simulations in chapter 3. Table (4.1) shows that when increasing the frequency at a constant load torque, the starting current decreases along with the starting torque, while the transient state period increases, which leads to delaying the stationarity [2].

Table (4.1) results of VVVF method at all case of the frequency

f (Hz)	Tload (%)	Ist (pu)	Tst (pu)	Transient (s)	Efficiency (%)	Power factor (%)
17	100	9.8	8.3	0.82	95	86
23	100	9.7	6.7	0.83	95	86
35	100	8.4	5.3	1	95	86

4.2 Direct starting results

Table 4.2 shows that when increasing the load torque the starting current decreases, while the starting torque increases along with the transient state, which leads to delaying the stationarity [2].

Table (4.2) results of the Direct starting method at all case of the load torque

Tload (%)	Ist (pu)	Tst (pu)	Transient (s)	Efficiency (%)	Power factor (%)
0	6.3	3.8	0.4	-	-
75	6.1	3.95	0.6	96	82
100	6	4.1	1.2	95	86

4.3 Soft starting results:

Table 4.3 shows that when increasing the load torque the starting current increases along with the starting torque, whereas the stationarity time is changing but not in a certain pattern [2].

Table (4.3) results of the Soft starting method at all case of the load torque

Tload (%)	Ist (pu)	Tst (pu)	Transient (s)	Efficiency (%)	Power factor (%)
25	4	0.75	1.3	97	55
50	5	1.6	1.22	97	72
75	5.8	2.6	1.15	96	82
100	5.9	3.45	1.45	95	86

4.4 General clarification of all the starting methods

Table 4.4 compares all the starting method at the nominal load, where the VVVF method will be taken at f = 17 Hz.

Table (4.4) results for all the method at the nominal load

Starting method	f (Hz)	Tload (%)	Ist (pu)	Tst (pu)	Transient (s)	Efficiency (%)	Power factor (%)
VVVF	17	100	9.8	8.3	0.82	95	86
Direct	50	100	6	4.1	1.2	95	86
Soft	50	100	5.9	3.45	1.45	95	86

The efficiency and the power factor are the same in all methods. However, they have no effect on the starting process, because they are taken after the transient state [2]. The transient state, on the other hand, has a rather significant effect on the starting process; since it determines the time the motor needs to reach stationarity. The VVVF method has a short transient, whereas the Soft starting method has a quite large one [2].

The starting torque of the Direct starting method is large and consistent at all torque loads, whereas it is fluctuating between small values and large ones in the Soft starting method. However, it gradually decreases when increasing the frequency in the VVVF method [2]. Last but not least, the starting current decreases when increasing the load in the Direct starting method, which is contrary to the increasing one in the Soft starting one. On the other hand, it decreases when increasing the frequency in the VVVF method [2].

All the starting methods simulated and studied in this report or the previous on are done in Matlab using the same motor model. Therefore, it is was possible to compare the results and make conclusions when changing only one or two parameters of the inputs and having the others as constants. In other words, it is quite difficult to compare this study with other studies for other motors with different parameters since it is conducted using a specific motor.

4.5 Conclusions

- The largest starting torque can be obtained from the VVVF method, while the smallest one from the Soft starting method.
- The Soft starting method requires the least starting current, whereas the VVVF method requires the largest.
- The longest transient state required to reach stationarity is found at the Soft starting method and the shortest is at the VVVF method.
- The efficiency and the power factor are almost identical at all the methods, since they are taken after the transient, where the starting methods actually differ.

To sum up, the VVVF method is used when a large starting torque is needed at a short transient state, keeping in mind the need of an external power source with an alternating frequency. In this simulating study, no losses occurred since they are mainly physical losses (cooling, switching, etc.), but these are considered as a disadvantage in real life and should be calculated. Whereas the Soft starting method provides a smooth startup without any jerks along with a controlled flawless acceleration. These features give the Soft starting method a reliable accuracy with less current needed at the expense of stationarity delay and external equipment charges. Finally, the Direct starting method is the most common one to start a 3ph induction motor due to its large starting torque without the need of external equipment [2]. From an economic point of view, it is cheaper to use the Direct starting method, because there will be no cost for external equipment, not to mention saving the maintenance cost in the future. When choosing a starting method, one should consider that the large starting current causes a disturbance to voltages on the supply lines, producing a severe voltage drop which affects the operation of other equipment [2].

Note: The fourteenth and fifteenth references are suggested to compensate for the eleventh reference which is in Arabic.

References

[1] A. Gonzalez, M. A. Arjona; New starting system for three-phase induction motors by using apart-winding and capacitors. Manchester, England: 7th IET International Conference, 2014.

[2] M.M.Abboud; Simulation of 3ph induction motor in Matlab with Direct and Soft starting methods. Sweden, Bachelor thesis, Linnaeus university, 2015.

[3] K. L. Shi, T. F. Chan and Y. K. Wong; Modelling of the three-phase Induction Motor using SIMULINK. Milwaukee, WI, Electric Machines and Drives Conference Record, 1997. IEEE International, 1997.

[4] B. Vahidi, M. R. Bank Tavakoli; Simulation of Ward Leonard Test Set and Induction Motor on MATLAB for Teaching Performance Characteristics of Induction Motor to Undergraduate Students, Wiley Periodicals, Inc. Comput Appl Eng Educ, 2009.

[5] Shinji Shinnaka: New Mathematical Models of an Induction motor using a minimum number of parameters. Scripta Technica, Electr Eng Jpn, 1998.

[6] Konstantinos N. Gyftakis, Member, IEEE, and Joya C. Kappatou, Member, IEEE; The Zero-Sequence Current as a Generalized Diagnostic Mean in Δ-Connected Three-Phase Induction Motors. IEEE Transactions on Energy Conversion (Volume:29 , Issue: 1), 2013.

[7] Mansour Ojaghi, Mahdi Sabouri and Jawad Faiz; Diagnosis methods for stator winding faults in three-phase squirrel-cage induction motors. John Wiley & Sons, Ltd, 2013

[8] Xin Xue and V. Sundararajan; THE APPLICATION OF WIRELESS SENSOR NETWORKS FOR CONDITON MONITORING IN THREE-PHASE INDUCTION

MOTORS. Nashville, TN, Electrical Insulation Conference and Electrical Manufacturing Expo, 2007.

[9] A.M.Elsaadawi- A.E.Kalas and M.Fawzi; DEVELOPMENT OF AN EXPERT SYSTEM TO FAULT DIAGNOSIS OF THREE PHASE INDUCTION MOTOR DRIVE SYSTEM. Aswan, Egypt, Power System Conference, 2008. MEPCON 2008, 12th International Middle-East.

[10] Mohammad H. Moradi, Pouria G. Khorasani; Anew Matlab Simulation of Induction Motor. Sydney, NSW, Power Engineering Conference, 2008. AUPEC '08, Australasian Universities, 2008.

[11] H. Boghos and A. Al Jazi, Asynchronous Machines. Damascus, Syria: DU, 2007.

[12] P. Stekl, 3-Phase AC Indudction Vector Control Drive with Single Shunt Current Sensing. Czech Republic: Freescale Czech Systems Laboratories, 2007

[13] N. Mohan, Advanced electric drives analysis control and modeling using matlab / simulink. Hoboken, New Jersey: John Wiley & Sons,Inc, 2014.

[14] C. Ong, Dynamic Simulation of Electric Machinery. West Lafayette, Indiana: Upper Saddle River, N.J. : Prentice Hall PTR, 1998.

[15] Krause, P. C., ‘Simulation of symmetrical induction machinery’, IEEE T rans. Power Apparatus Systems, Vol. PAS-84, No. 11, 1965.

Appendix

Notes:

The simulations are not run by the m-file but are run by the Simulink models. However, the process goes by these steps:

1. The m-file is opened and run, which stores the values at Matlab datasheet to be used when needed in the Model.

2. Then the model is opened and run as well, and the parameters which are not defined in the model are taken as values from the datasheet.

3. The main system in figure (3.2) has three inputs and five outputs, while the subsystem has only two inputs and five outputs. The main system inputs are the three phase voltages implemented as equations. The objective is to represent these voltages on Alpha Beta coordinates system as two voltages, using simple conversion equations.

4. The subsystem -on the other hand - represents the equations found on pages (14-16) as blocks, to process and preview them as outputs. For instance, the current i_α^s can be easily substituted by a simple integration and 3 gains (1/Ls, Rs/Ls, M/Ls), and then its value could be taken from the current curves since each current has a unique color. The same method is used on all the blocks to produce the outputs, which can be previewed by double clicking on the wanted icon in the main system.

5. If the reader would like to run the tests again he should make the changes (in the starting voltage for example) in the model instead of the code since there is no code. This could be more difficult than the standard way, but it is easier when making the simulations for the first time.

6. Regarding the current equations found on page (14), they are slightly different from the ones found in reference [13] since Mohan has introduced his equations according to (qd) coordinates. Note that in order to use Mohan's equations the axis (Alpha) should be considered as the axis (d) and the axis (Beta) as (q). For instance, i_α^s corresponds to i_d^s and i_β^s corresponds to i_q^s and so on.

Matlab simulation code

```
%DATA OF A THREE PHASE INDUCTION MOTOR

%Pn=18.5 kW;

M=0.0489; %H mutual inductance

Rr=0.16; %ohm the rotor resistance
```

```
Ls=0.05; %H the stator inductance

Lr=0.051; %H the rotor inductance

Rs=0.159; %ohm the stator resistance

P=2; % the number of pairs of poles

J=0.234%KGM2  % moment of inertia

Wrb=314; % 2πf

Tb=125; % the nominal torque

Ib=52; % the nominal current

Tfactor1=((3/2)*M*P);

Tfactor2=(P/(J));
```

Hi
I have started my journey with electrical engineering in Syria 2008 and graduated from LNU, Sweden in 2015. I have had a career in water polo as a player and a trainer and really excited to start my career in engineering.

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