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Studying the Performances of Induction Motor Used in Electric Car

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Abstract

This research includes study of the performances of induction motor used in the electric car, as well as performances of an electronic inverter based on Field Oriented control used to drive this induction motor.
The running equations of IM and Controller in dynamic state with reference frame d – q were considered. These equations were modelled into computer form based using Matlab Simpower facilities obtaining a complete model. 3-Phase IM is considered and its parameters were used for simulation, in order to be mounted in certain car that is manufactured in Syria, and transform it to electric car.
Also, it includes a study of electronic inverter appropriate to drive such motor and control its speed. It operates based on vector control technology.
The study of the motor performances was conducted within presumptions of changing car load from one passenger (the driver) to five passengers and having different resistant torques.
The tests of induction motor used in the electric car simulate running of the car having one passenger when car is stopped; simulate running of electric car starting IM from 0 speed and accelerating till a steady speed is reached, keeping this steady speed for a period of time, then reduce speed till car is stopped and finely Simulate running of electric car on rural roads having some holes and small slopes which cause several small acceleration and sudden breaks.
Some conclusions and remarks about performances and behaviour of IM were concluded.

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Key words: Three phase induction motors; electronic inverters; simulation; electric car.

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1. Introduction:

Great developments related to the systems of alternating-current motor driving helped in fast spread of induction motors in so many applications of industrial & technological operations. It occupied a prominent position compared with direct-current motors [6]. The IM has the advantages:

- IM has no collector and no brushes so it needs less maintenance
- Cost of IM is less than cost of DC motors for the same nominal power.
- Weight of IM is less than weight of DC motors for the same nominal power.
- IM is more robust than DC motors and can works better in abnormal ambient conditions.
- IM can be manufactured for nominal voltage till 25 KV.
- IM can be manufactured for bigger power and can reach a rotation of 50000 rpm.

Within such framework, this research seeks to study the performances of induction motor used in the electric cars, as well as the performances of the controller used to drive this induction motor, which realizes best results. This controller should be manufactured easily, with low cost, and operates as per most recent driving and controlling theories of induction motors, the most adequate and modern is Field Oriented Control FOC [2].
This research includes study of the performances of three-phase induction motor including the electronic inverter to drive such motor and control its speed, in order to be mounted in certain car that manufactured in Syria, and transform it into electric car. The study of the motor performance was conducted within presumptions of changing car load from one passenger (the driver) to five passengers; as well as studying motor performance in road changing slope, having the car loaded with different number of passengers; car considered moving on normal streets and on country roads.

2. Modeling and Simulation of Induction Motor used in Electric Cars

The use of reference frame axis transformations in electrical machines realizes reduction of running equations nr from 3 to 2, which helps to simplify the modeling and simulation of electrical machines and their control. To realize the transformation from a, b, c frame to d – q frame the following matrices are used. In special case when the field angel is θ = 0, these matrices became:

$$[C]^{-1} = \begin{bmatrix} \sqrt{\frac{2}{3}} & -\frac{1}{\sqrt{6}} & -\frac{1}{\sqrt{6}} \\ 0 & \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} \end{bmatrix} \qquad [C] = \begin{bmatrix} \sqrt{\frac{2}{3}} & 0 & \frac{1}{\sqrt{3}} \\ -\frac{1}{\sqrt{6}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{3}} \\ -\frac{1}{\sqrt{6}} & -\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{3}} \end{bmatrix}$$

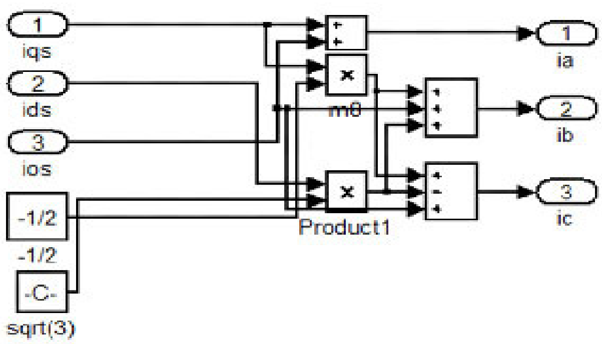

Fig.1 Computer model for transformation
from 2 axis frame d – q to 3 axis frame a, b, c

In Fig.1 is given the computer model used to perform the transformation from 2 axis frame d – q to 3 axis frame a, b, c. In Fig.2 is given the computer model used to perform the transformation from 3 axis frame a, b, c, to 2 axis frame d – q .

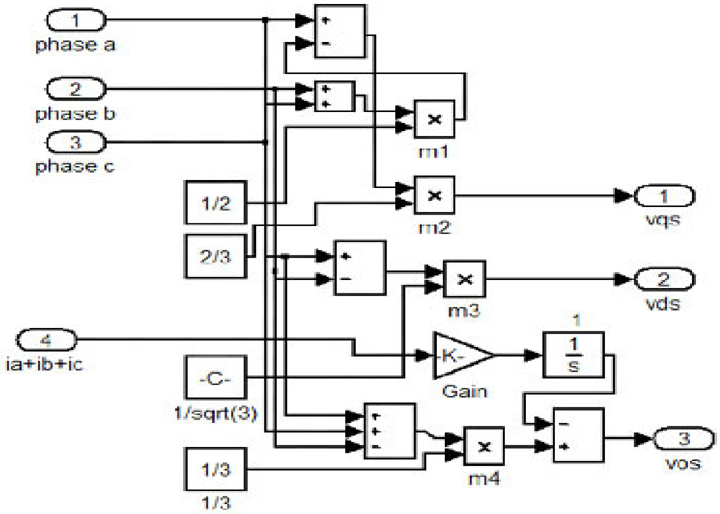

Fig.2 computer model transformation from
3 axis frame a, b, c, to 2 axis frame d – q

In Fig.3 is given the equivalent electric circuit for on phase of three- phase IM raported to stator.

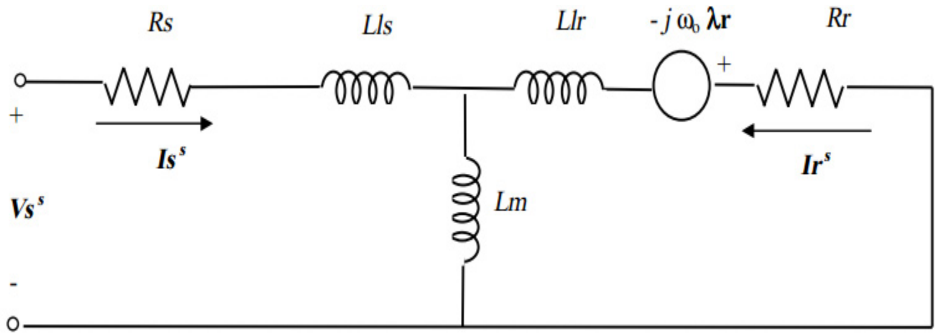

Fig.3 Equivalent electric circuit for on phase of three- phase IM raported to stator.

Based on the following running equations of IM in d – q frame, the dynamic model of IM was established as given in Fig.4: [4]

$$\psi^{s}_{qs} = w_b \int v^{s}_{qs} + \frac{r_s}{x_{ls}} (\psi^{s}_{mq} - \psi^{s}_{qs}).dt \quad \psi'^{s}_{qr} = w_b \int v'^{s}_{qr} + \frac{w_r}{w_b}.\psi'^{s}_{dr} \frac{r_s}{x_{ls}} (\psi^{s}_{mq} - \psi'^{s}_{qr}).dt$$

$$\psi^{s}_{ds} = w_b \int v^{s}_{ds} + \frac{r_s}{x_{ls}} (\psi^{s}_{md} - \psi^{s}_{ds}).dt \quad \psi'^{s}_{dr} = w_b \int v'^{s}_{dr} - \frac{w_r}{w_b}.\psi'^{s}_{qr} \frac{r_s}{x_{ls}} (\psi^{s}_{mq} - \psi'^{s}_{dr}).dt$$

$$i^{s}_{qs} = \frac{\psi^{s}_{qs} - \psi^{s}_{mq}}{x_{ls}} \qquad i'^{s}_{qr} = \frac{\psi'^{s}_{qs} - \psi^{s}_{mq}}{x_{lr}}$$

$$i^{s}_{ds} = \frac{\psi^{s}_{ds} - \psi^{s}_{md}}{x_{ls}} \qquad i'^{s}_{dr} = \frac{\psi'^{s}_{ds} - \psi^{s}_{md}}{x_{lr}}$$

$$\frac{1}{x_M} = \frac{1}{x_m} + \frac{1}{x_{ls}} + \frac{1}{x_{lr}} \qquad v^{s}_{qs} = \frac{2}{3}v_{as} - \frac{1}{3}v_{bs} - \frac{1}{3}v_{cs} = \frac{2}{3}v_{ag} - \frac{1}{3}v_{bg} - \frac{1}{3}v_{cg} - v_{sg}$$

$$\psi^{s}_{mq} = x_M\left(\frac{\psi^{s}_{qs}}{x_{ls}} + \frac{\psi'^{s}_{qr}}{x_{lr}}\right) \qquad v^{s}_{ds} = \frac{1}{\sqrt{3}}(v_{cs} - v_{bs}) = \frac{1}{\sqrt{3}}(v_{cg} - v_{bg})$$

$$\psi^{s}_{md} = x_M\left(\frac{\psi^{s}_{ds}}{x_{ls}} + \frac{\psi'^{s}_{dr}}{x_{lr}}\right) \qquad v_{0s} = \frac{1}{3}(v_{as} + v_{bs} + v_{cs}) = \frac{1}{3}(v_{ag} + v_{bg} + v_{cg}) - v_{sg}$$

$$T_{em} = \frac{3}{2}\frac{P}{2w_b}(\psi^{s}_{ds}.i^{s}_{qs} - \psi^{s}_{qs}.i^{s}_{ds})$$

$$J.\frac{dw_{rm}}{dt} = T_{em} - T_{mech} - T_{damp}$$

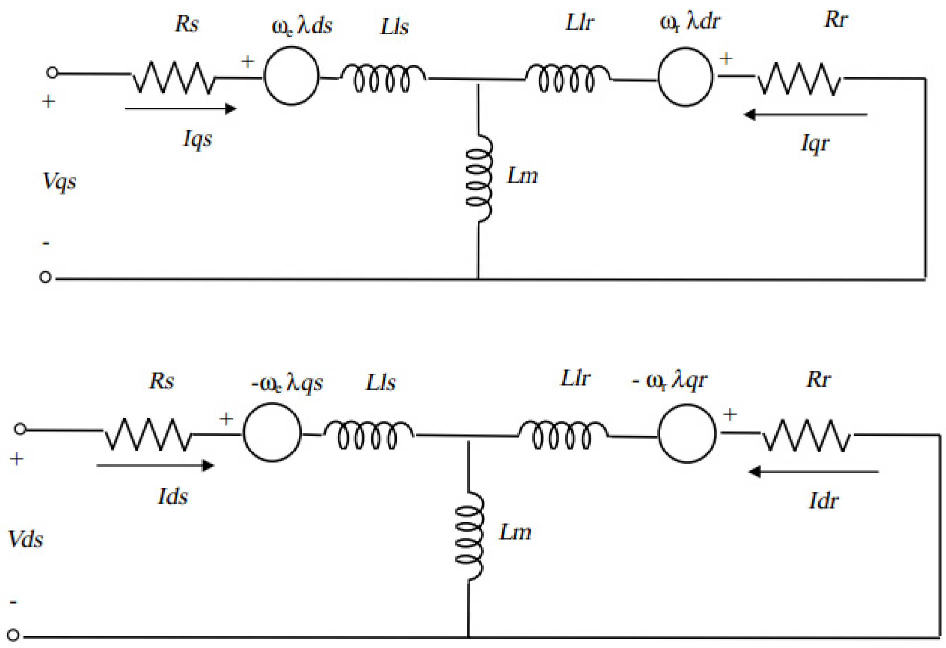

Fig.4 Equivalent electric circuits of IM in d – q frame

A three phase electronic inverter based on FOC was used to control the speed of IM. In Fig. 5 is given the simulation model of the controller used with IM to control rotation speed based on FOC. [1] [2]

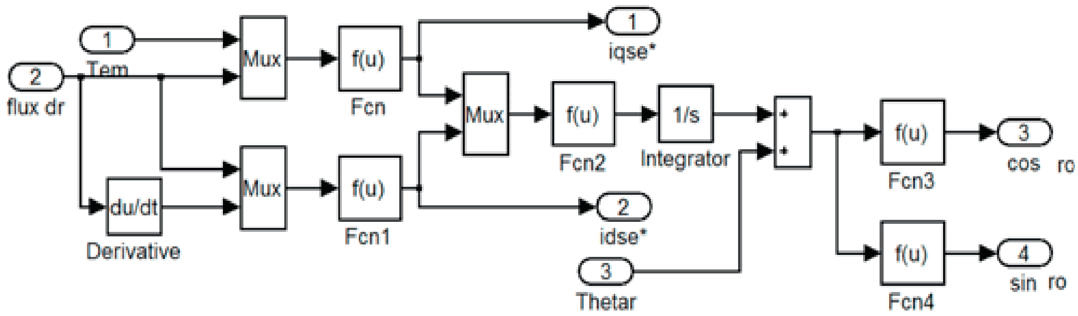

Fig.5 Simulation model of rotation speed controller

The torque equation was modelled as given in Fig.6 and the zero sequence component of the current is modelled as given in Fig. 7. [3]

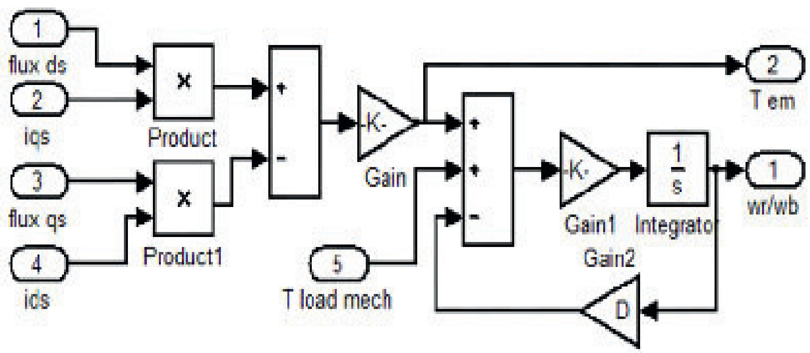

Fig.6 Computer modelling of torque equation

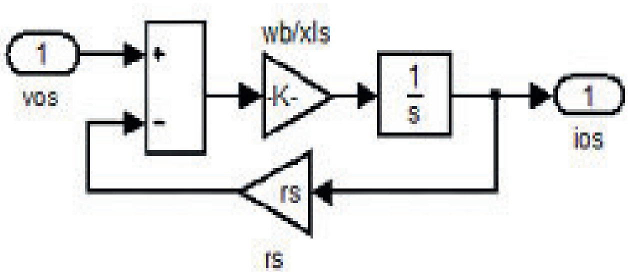

Fig.7 Computer model of zero sequance current

3. Simulation of the induction motor and the inverter:

The study cases of induction motor used in the electric car was conducted in several proposals in which cases the IM is considered running in no - load on its axis while car is stopped; running with different loads; running from 0 speed and accelerating till steady speed is reached and maintained for a period of time and then reduced till rest and

the IM stops; running on rural roads having holes and small slopes which cause several small acceleration and sudden breaks.
A three phase IM having the following parameters shown in table.1 was simulated and tests were carried using the computer model of the IM and its controller.

Table.1 Parameters of IM.

Vn = 96 V	Power factor= o.8	Pout= 10.5 Kw	F = 50 Hz	Poles = 4	D (damp factor)
Rs = 0.12 Ohm	Rr = 0.18 Ohm	Ls = 0.123 mH	J = 0.102 Kg.m^2	Lr = 0.385	0.01 N.m/ra.s^{-1}

3.1. Simulation the running of IM without load on its axis, while car is stopped. In Fig.8 are given variations in time of torque and rotation speed of IM.

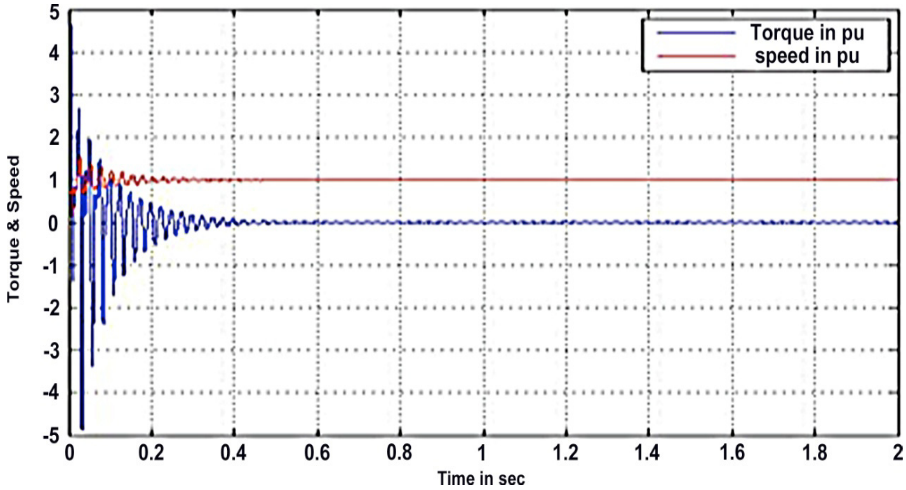

Fig.8 Variation in time of rotation speed and torque
of IM motor operating without load on its axis

Fig. 8 shows the simulation results of IM operating without load on its axis, torque and rotation speed varying in time are given. The starting torque reached the value of 4.8 pu in compression with active torque and this value is in admissible limits of IM characteristics. The rotating speed is varying in time accordingly reaching 1.5 pu. The transient time till active torque and rotation speed became steady is 0.5 sec. Torque and rotation speed curves show that after transient period rotation speed in this case is 1 pu and active torque is 0.15 pu, this torque needed to cover resistant torque while car is stopped.

3.2. Simulation the running of IM applying different load torques considering the weight of empty car which is 1150 kg. the weight of driver and 4 passengers which is 400 kg; and also considering torque of wheels friction on road and torque of wind pressure on front of car.
In Fig.9 are given variations in time of torque and rotation speed of IM when a load torque equal to 100% of the nominal torque of IM. In Fig.10 are given variations in time of torque and rotation speed of IM when a load torque equal to 50% of the nominal torque of IM is applied.
The value of starting torque, in all these cases is very big reaching about 16 times nominal torque, but it last for transient time of less than o.2 sec. and can be sported easily by IM. After a transient period the active torque value became stable. Figs. show also that rotating speed is varying accordingly from 0 to 3500 rpm and after a transient period of 0.5 sec rotating speed is stabilized at nominal rotation speed of 2950 rpm. These results show the capability of tested IM to satisfy variable load torque of the electric car and can ensures necessary torque needed for electric car traction.

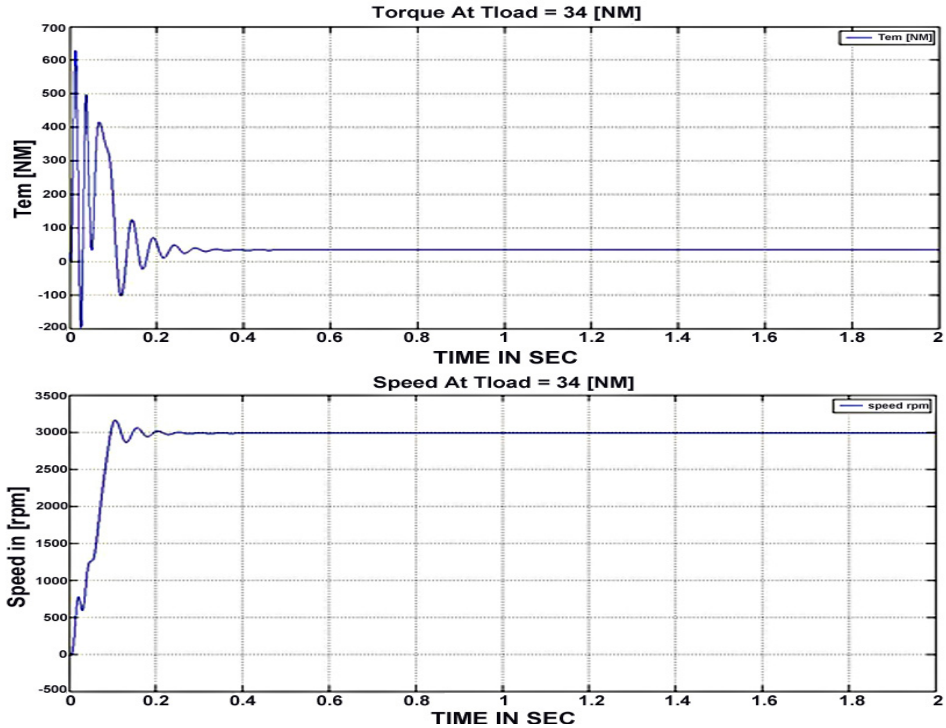

Fig.9 Variation in time of rotation speed and torque of IM motor
when a load torque equal to 100% of nominal torque is applied

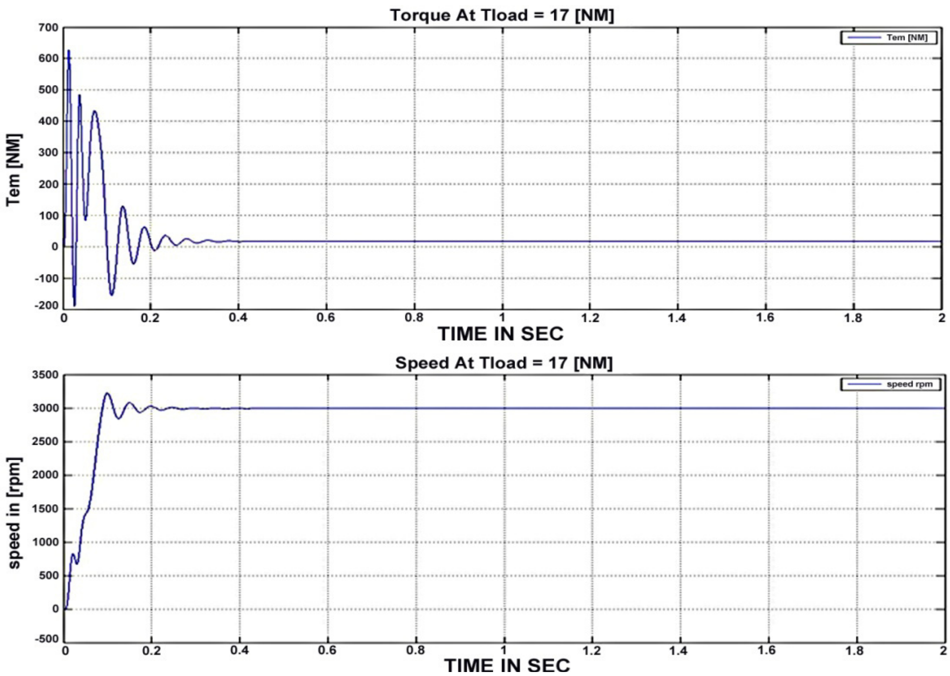

Fig.10 Variation in time of rotation speed, torque of IM motor
when a load torque equal to 50% of nominal torque is applied

3.3. Simulation the running of IM when car is moving with constant acceleration to reach steady speed fixed by car's driver, running for a while on this steady rotating speed then reduce the speed till 0, the car is stopped and the motor is in no load running. In Fig.11 are given variations in time of torque and rotation speed of IM when a load torque equal to 50% of the nominal torque of IM is applied .In Fig.12 are given variations in time of torque and rotation speed of IM when a load torque equal to 100% of the nominal torque of IM is applied.

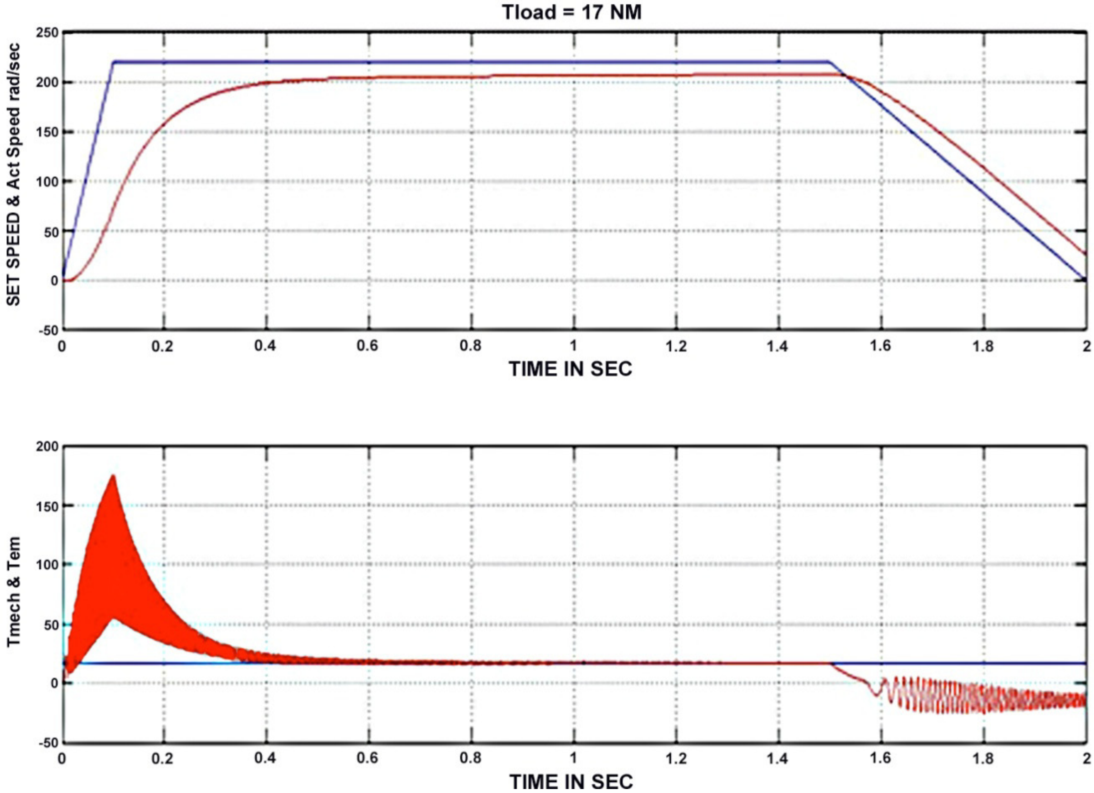

Fig.11Variations in time of torque and rotation speed of IM
when a load torque equal to 100% of the nominal torque

Fig.11 and Fig.12 show the simulation results of IM driving the car when a constant acceleration is applied to increase rotation speed to reach the steady speed, after running a period of time on this speed, active torque is reduced and so rotation speed, till car is stopped and electric motor is without load torque on its axis.

It can be noticed in Fig.11 that value of starting torque reached 170 N.m in compression with active torque 34 N.m, which is in admissible limits of IM characteristics. The transient time till active torque and rotation became stable is o.6 sec.

It can be noticed in Fig.12 that value of starting torque reached 190 N.m in compression with active torque 34 N.m, which is in admissible limits of IM characteristics. The transient time till active torque and rotation became stable is o.8 sec.

3.4. Simulation the running of IM when car is moving on country roads having holes and small slopes, forcing the driver to change speed of car, accelerating and breaking, applying different load torques. IN fig.13 are given variation in time of torque and rotation speed of IM when a load torque equal to 100% of the nominal torque. IN fig.14 are given variation in time of torque and rotation speed of IM when a load torque equal to 50% of the nominal torque and load torque is applied.

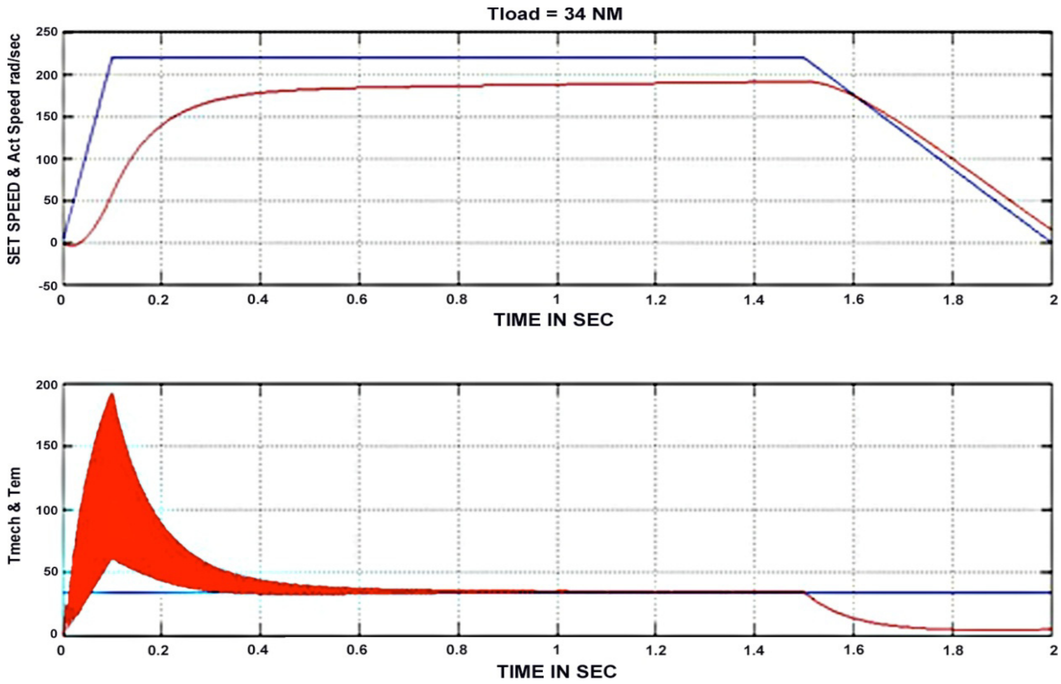

Fig.12 Variations in time of torque and rotation speed of IM
when a load torque equal to 50% of the nominal torque

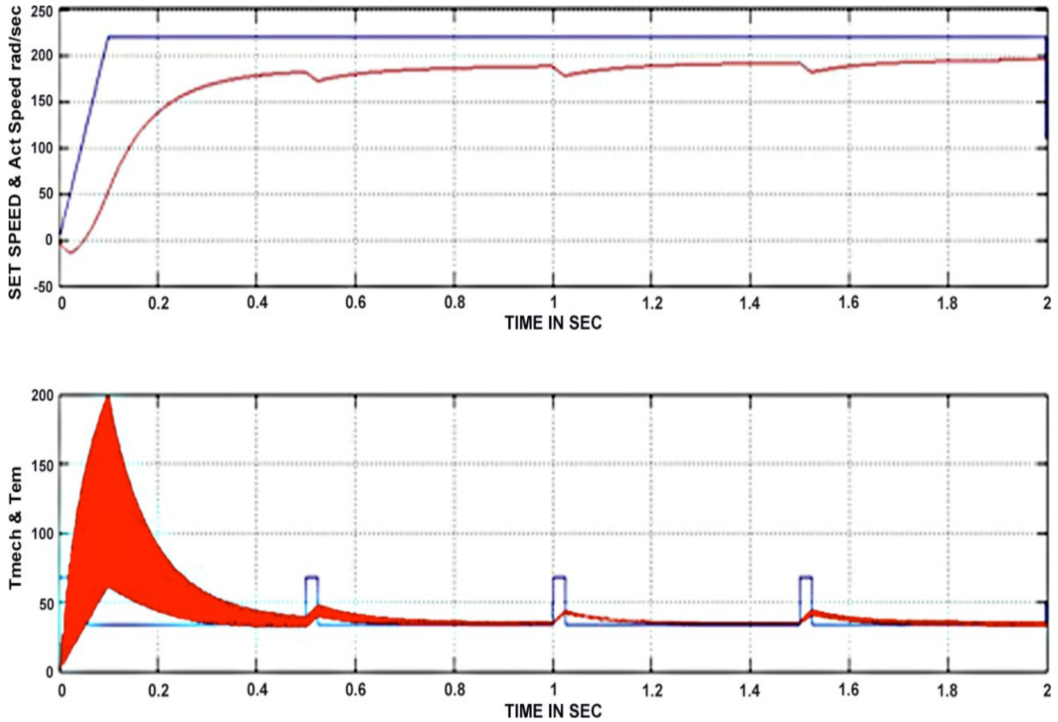

Fig.13 Variation in time of rotation speed and torque of motor
for 100% load torque when car moving on country road

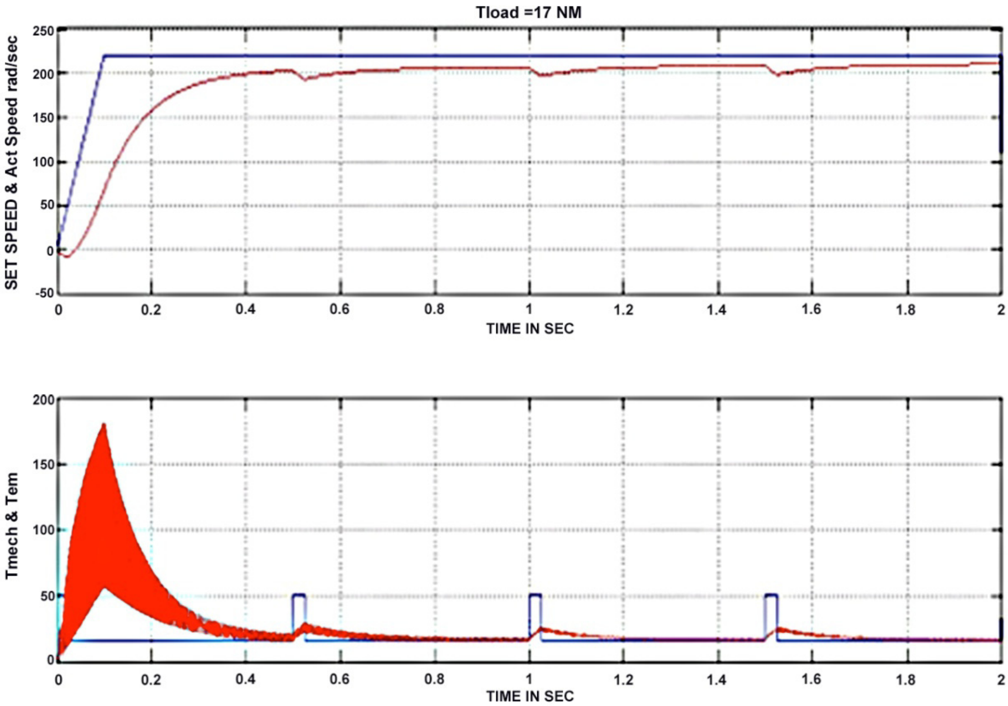

Fig.14 Variation in time of rotation speed and torque of motor for 50% of load torque when car moving on country road

Fig.13 and Fig.14 show simulation results of IM driving the car when car started from 0 speeds and is running on a country road with a lot of small holes and slopes forcing driver to give IM small acceleration on slopes and small breaks on holes. It can be noticed that active torque increased when a small slope is simulated.

4. Conclusions:

- The IM reaches steady state having constant rotation speed after a transient period which not exceeding 0.4 s in all loading cases of the car. This confirms that the IM is suitable to be used in electric car.
- The maximum phase current, when different load torques are applied is 200 A, which is less than nominal current.
- The current of IM is increasing proportional to the slope angel value.
- When rotating speed is reduced till stop during running, IM may change its state and run as induction generator; current absorbed became negative.
- The behaviour of the tested induction motor in all running proposed cases of the car is very satisfactory encouraging its use in a car manufactured in Syria.

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