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Static and Dynamic Load Generator based on Induction Motor

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Abstract: Implementation of complex test for electrical machines usually demands special experimental equipments. To meet this end, electrical machines test benchs are designed and constructed. In this system different industrial load characteristic are generated for test machine and its drive using a dynamometer . In this paper an induction motor vector controlled load generator based on torque tracking control method, is proposed as load generator. In this method, a direct power control PWM rectifier, guarantee the four-quadrant operation of dynamometer. For investigation of proposed dynamometer performance, different parts of this system are simulated in SIMULINK/MATLAB and the Simulation results are presented.

Keywords: Dynamometer, Indirect vector control, direct controlled PWM rectifier, Test bench

1 Introduction

Modern industrial variable speed drive systems are a complex combination of an electrical machine ,a power electronic device, and a digital processor system, executing a control algorithm. Such device can be used in applications where open loop control is employed, or alternately they can be used in applications where high precision servo performance is desired. industrial process often contain non-linear mechanical loads drived by electrical drives. It is desirable to be able to test the overall performance of the total drive system combination, under controlled conditions, in the laboratory for desired industrial load profile. For this purpose a electrical machine test faculties have been used. Test bench of electric machines made of three part: dynamometer and its control system, data acquisition system and motor (or drive) under test [1,2,3]. dynamometer are commonly used during the development process of a drive system in order to assess its performance ,in part because it is not always practical to test it directly with the actual load. Hence rotating machinery can be tested on this dynamometer to determine their transient and steady-stead characteristic with a practical load. In Classical dynamometer the load is adjusted by altering the frictional drag or the electrical output of the generator ,or by varying the slip of the clutch .in both case ,the load is passive and the machine under test can only be tested under steady –stat loading condition. In [1,2] dynamic load generator (dynamometer) implemented using a DC motor and based on reference model control. In this methods, it is necessary to know the accurate model of the under test motor. In [4,5,6] dynamometer control done in closed loop manner. In this way under test motor and drive is a component part of the closed loop control system and required to measurement the motor under test electrical torque. In this method the electric torque of under test motor should be measured, that isn’t desired. In this paper at first, static and dynamic characteristics of mechanical load are studied. In order to produce arbitrary loads profile, it is assumed that torque characteristics of arbitrary load versus speed is known, and The user inputs the desired load characteristic by selecting polynomial and inertia coefficient. Then by measuring speed, the reference torque is produced. For tracking such reference torque, an indirect vector control drive system force the torque of load generator motor on reference value. To achieve four-quadrant operation of the dynamometer, the load generator drive must capable to send the power back to the grid in generator mode. For this purpose, a direct control PWM rectifier topology is used. To study of the proposed method ,a precise model of different parts of such system are simulated in SIMULINK/MATLAB and some typical industrial load, both static and dynamic, generate and imposed on under test motor . Several Simulation results show that the static or dynamic characteristic of industrial linear or nonlinear loads can be modeled, precisely, for motor and drive under test.

2 Static and dynamic characteristic of typical load

To produce desired load profile, first different component part of the load must be known. Basically, torque characteristics of the load can be divided to two component part which are: static and dynamic component. So according to[7,8,9] we can written as:

$$T_l = T_d + T_s \tag{1}$$

Static component, present load torque in any steady state speed. Static torque characteristics as stated in equation(2) is a function of speed.

$$T_l = \sum_{n=-\infty}^{\infty} A_n \omega_m^n \tag{2}$$

In this equation T_l is the static torque of the load in $N.m$, ω_m is angular speed of the motor in $rad/\sec$ and A_n are constants that are chosen according to the load characteristics manually . For any load the A_n constants must be chosen in such way that can describe torque speed characteristics for whole speed range. The dynamic characteristics of the load show the load torque in the accelerating and decelerating duration. Following equation gives dynamic torque for the rotational body.

$$T_{ld} = J_L \frac{d\omega}{dt} \tag{3}$$

Where ω_m is angular speed and $d\omega_m/dt$ is angular acceleration and J_l is the inertia moment of the body. angular acceleration value in accelerating duration is positive and this dynamic torque is added to the load torque. In the deceleration duration, this term is negative and resultant dynamic torque is added to the dynamometer torque and in steady state, this term of load torque is zero. The general equation for torque-speed characteristics of the load is:

$$T_l = T_{ld} + T_{ls} = J \frac{d\omega_m}{dt} + \sum_{n=-\infty}^{\infty} A_n \omega_m^n \tag{4}$$

As shown in fig.1 if the electric drive rotated a mechanical load , we have:

$$T_m - T_l = J_m \frac{d\omega}{dt} + D_m \omega_m \tag{5}$$

$$T_l = J_l \frac{d\omega_m}{dt} + \sum_{n=-\infty}^{\infty} A_n \omega_m^n + D_m \omega_m \tag{6}$$

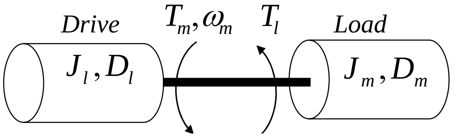


Fig.1 Electrical drive and mechanical load system

Where T_l and T_e are load and motor torque, J_l and J_m are load and motor inertia moment and D_l and D_m are load and motor friction constant respectively. Substituting 5 in 6 results:

$$T_m = J_m \frac{d\omega_m}{dt} + D_m \omega_m + J_l \frac{d\omega_m}{dt} + \sum_{n=-\infty}^{\infty} A_n \omega_m^n + D_l \omega_m \tag{7}$$

$$T_m = J_T \frac{d\omega_m}{dt} + \sum_{n=-\infty}^{\infty} A_n \omega_m^n \tag{8}$$

Where $D_l \omega_m$ and $D_m \omega_m$ can be combined in term $\sum_{-\infty}^{+\infty} A_n \omega_m{}^n$.

As result, above mentioned equation could be stated as:

$$t_e = J_t \frac{d\omega_m}{dt} + \sum_{n=-\infty}^{\infty} A_n \omega_m^n \tag{9}$$

3 dynamometer control method

Basically, in a electrical test bench a dynamometer substituted a real load. A dynamometer must be able to produce torque speed characteristics of different load at static and dynamic state. Fig.2 show a under test electrical machine(MUT) and load generator motor(LGM). In this system, a real load in fig.1 substituted with a electrical motor . in this system we should control the LGM motor such that the real load condition provide for MUT motor.

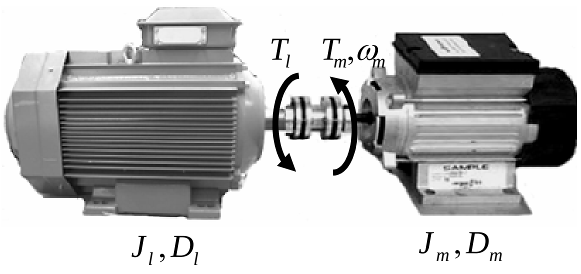


Fig.2 Motor under test and load generator motor system

Regarding to equation (4) the arbitrary mechanical load can be expressed as:

$$T_{load}^{*} = A_0 + A_1\omega_m + A_2\omega_m^2 + A_3\omega_m^3 + \ldots\ldots \qquad (10)$$

$$+ J_{em}\frac{d\omega_m}{dt} + D_{em}\omega_m$$

Where, $A_0, A_1, \ldots, A_n$ are constants, J_{em} is inertia moment that dynamometer must generate and ω_m is a measured angular velocity ($rad/\sec$). The block diagram of an induction motor vector controlled load generator based on torque tracking control method is shown in fig.3. in this system the shaft speed is measured and $A_0, A_1, \ldots, A_n$ and J_{em} defined by operator. hence we can calculate the reference torque (that dynamometer must model for under test motor), determined from eq.(10). This torque consist of static and dynamic term, that are proportional with angular speed and its derivative respectively. For such system can write:

$$T_m - T_{ls} = \left(J_m + J_l\right)\frac{d\omega_m}{dt} + (D_m + D_l)\omega_m \qquad (11)$$

Where $\mathrm{T_m}$ is electric torque of the MUT and T_{lS} is static torque of the LGM. The actual torque that dynamometer yields to the shaft is:

$$T_{load\ -real} = T_l + J_l\frac{d\omega_m}{dt} + D_l\omega_m \qquad (12)$$

Where $J_l\frac{d\omega_m}{dt} + D_l\omega_m$, is dynamic torque results from the inherent behavior of LGM. If the desired dynamic torque that dynamometer must produced be $J_{em}\frac{d\omega_m}{dt} + D_{em}\omega_m$ then the actual reference dynamic torque that dynamometer must produce will be:

$$T_{dynamic-real} = (J_{em}\frac{d\omega_m}{dt} + D_{em}\omega_m) - \qquad (13)$$

$$(J_l\frac{d\omega_m}{dt} + D_l\omega_m)$$

So the total reference torque must be:

$$T_{load-real}{*} = A_0 + A_1\omega_m + A_2\omega_m^2 + A_3\omega_m^3 + \ldots\ldots \qquad (14)$$

$$+(J_{em}\frac{d\omega_m}{dt} + D_{em}\omega_m) - (J_l\frac{d\omega_m}{dt} + D_l\omega_m)$$

Final equation will be as follow:

$$T_m - T_{load-real} = J_m\frac{d\omega_m}{dt} + D_m\omega_m \qquad (15)$$

Where:

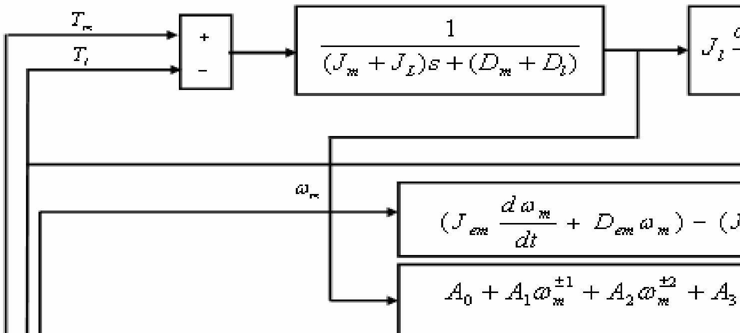
$$\omega_m = \frac{1}{(J_m + J_L)s + (D_m + D_l)}(T_m - T_l) \qquad (16)$$

4 Load generator controller structure

As explain before, in proposed method, for any arbitrary load characteristics, a reference torque product from eqs. 11 to 16 according to block diagram of fig.3. In this paper a three phase squirrel cage induction motor is used as load generator. To track this reference torque, an indirect vector control strategy using VSI-inverter is implemented. Fig.4 shows the control structure of LGM's control system. In order to test the MUT motor in any conditions it is important that The LGM motor drive be capable to operate at four-quadrant of the torque speed plan. Because of well known advantage of PWM rectifier, we implement a direct power controlled PWM rectifier as rectifier in front-end of drive system. The DPC/PWM rectifier has many advantages than classical rectifier (diode rectifier), such as: DC link voltage control at different operating condition, power recovery capability, sinusoidal input current and high power factor at AC side. Hence The proposed fast dynamic four-quadrant torque tracking system, provide an appropriate controller for LGM in industrial load generation.

5 Modeling and simulation results

To investigate performance of dynamometer Control system shown in fig.3, such system is simulated in SIMULINK/MATLAB and simulation result for several typical load presented in each case. In this study an induction motor with parameters given in index is used. To verify the performance of torque tracking control strategy, the simulation performed for a time varying reference torque. Fig.5 show the reference torque, electrical torque , speed and stator current in this condition. Simulation result shows that the indirect vector control torque tracking strategy have appropriate accuracy and fast dynamic. For investigate the operation of LGM's control method ,some typical industrial load profile is generate to test a similar squirrel cage induction motor which fed bye a nominal three-phase voltage.



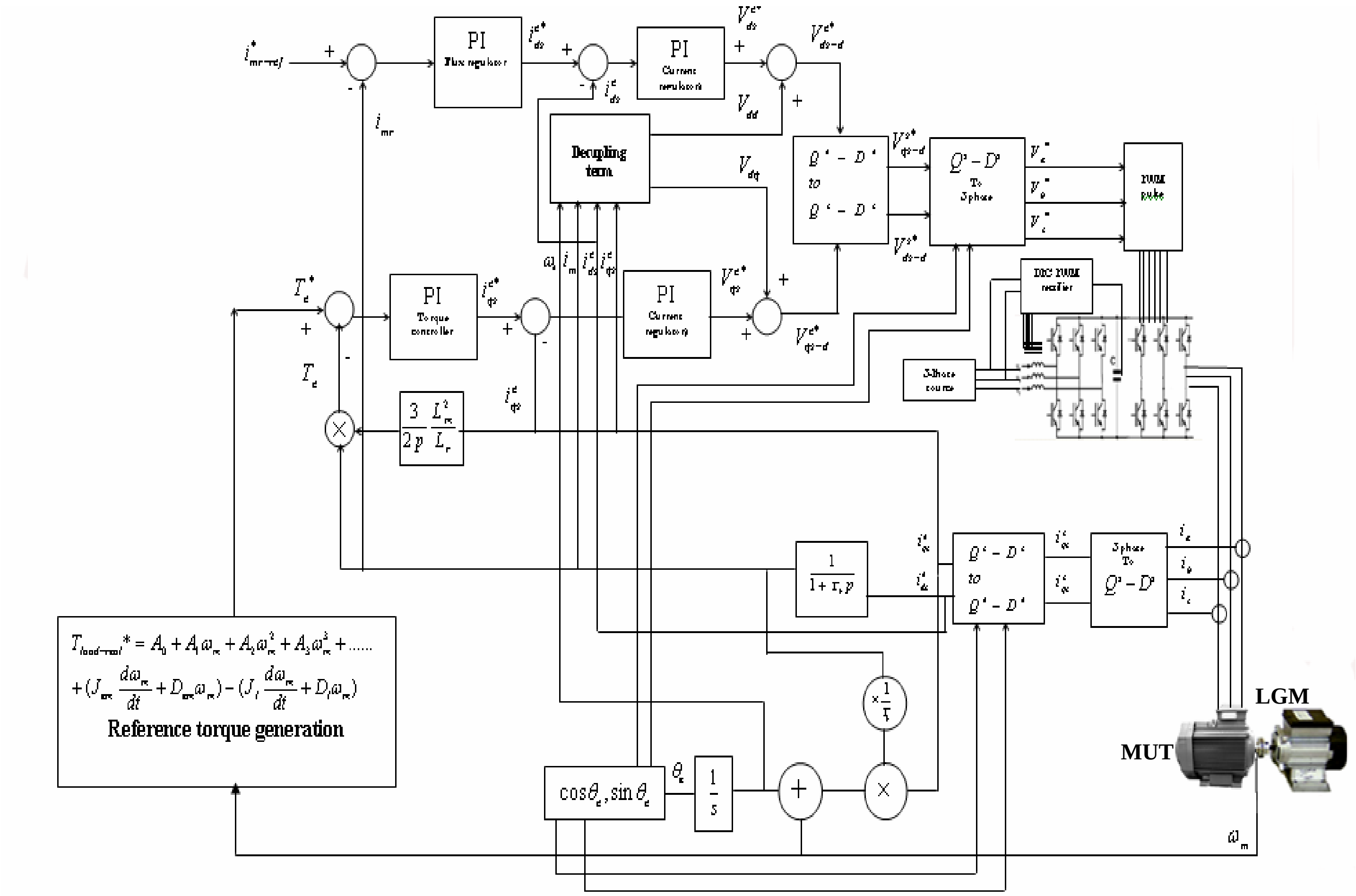
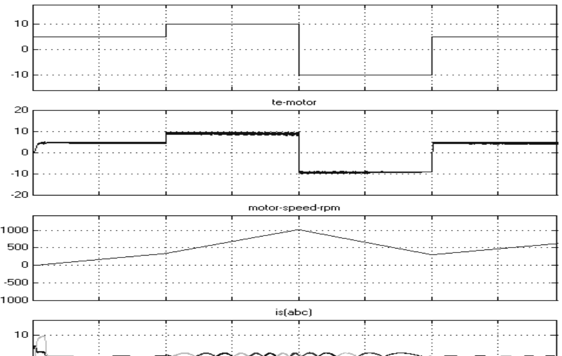


Fig.4 induction motor torque tracking vector control and front end direct power control PWM rectifier



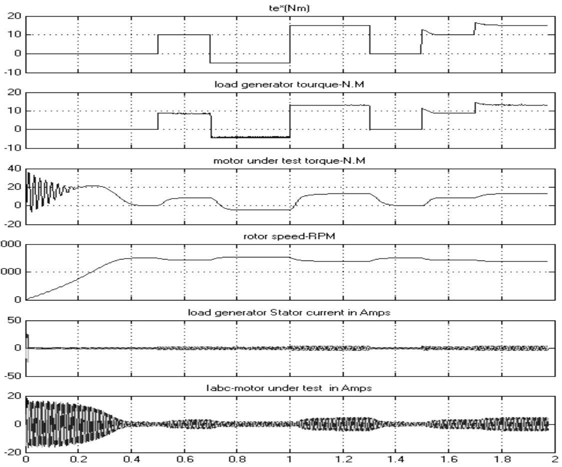


Fig.6 LGM's electrical torque, MUT's electrical torque, MUT's speed, LGM's stator current and MUT's stator current

Fig.6 shows simulation result of MUT test under time varying dynamic torque and time varying static constant torque. Simulation result constitute reference load ,LGM's electrical torque, MUT's electrical torque, MUT's speed,LGM's stator current and MUT's stator current.LGM's active power during test priod is shown in fig.7

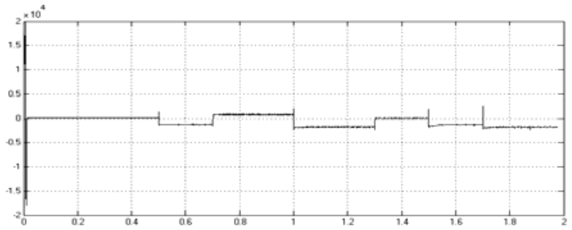


Fig.7 LGM's active power during test period

Fig.8,9 show the Simulation result for Induction motor free run test .in fig .8 the command inertia is less than the of LGM's moment inertia(J_l). As shown in fig.8 in this condition the LGM motor operate as motor and product negative breaking dynamic torque during acceleration .as shown in fig.9 for command inertia larg than the of LGM's moment inertia, the LGM product positive breaking dynamic torque during acceleration and increase acceleration time.

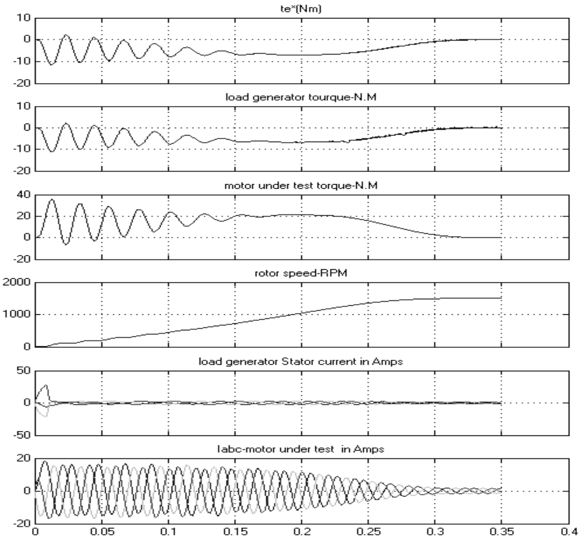


Fig.8 MUT free run test for dynamic load equal to:

$$T^*_{load} = J_l * 0.5 \frac{d\omega_m}{dt}$$

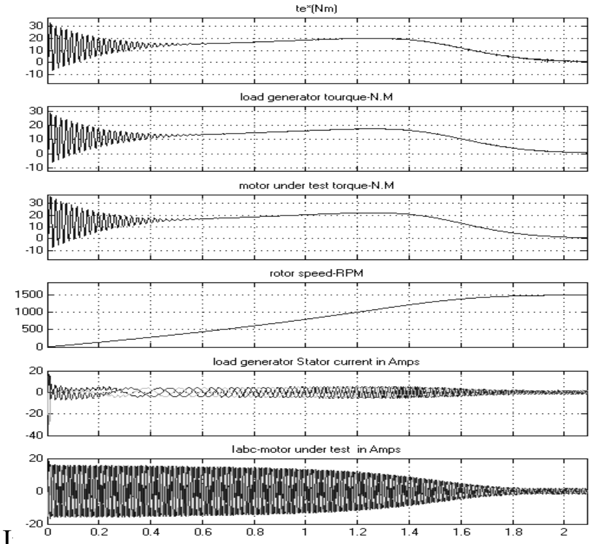


Fig.9 MUT free run test for dynamic load equal to:

$$T^*_{load} = J_l * 10 \frac{d\omega_m}{dt}$$

In another study (not shown) a constant torque load is simulated for two command inertia. When the command inertia is equal to the LGM's inertia, dynamic torque reference equal to zero. Hence the LGM's only product steady state torque that equal to 10N.m. But for less command inertia the dynamic torque is negative and adds to steady state torque. this shown that the acceleration is faster than the former case. the simulation result show that for very low dynamic torque command, the PI current controller of LGM will be saturated and practically it is impossible to achieve a very fast acceleration. To over came this problem it is necessary select a load generator motor with low inertia and large nominal value.

Conclusion

In this paper an induction motor vector controlled load generator based on torque tracking control method is used to modeling real industrial mechanical load for electrical machine test bed. This dynamometer utilized indirect vector control strategy and PWM rectifier, thus four-quadrant operation in torque speed plan is feasible. Considering good dynamic of this system, production of high order, linear or nonlinear load profile is possible in steady stead or dynamic condition. After simulation of dynamometer, several programmed load profile implemented. Simulation result for linear and nonlinear load profile in static and dynamic state illustrate that this system can model the arbitrary load profile with good accuracy.

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load generator and motor under test parameter:
Vn =380v,Rs=8.28 Ω , Rr=6.16Ω , Ls=9.91Ω , Lm=244.232Ω , J=0.02 Kg.m2, D=.001 n.m.s, Pn=3kw, *pf* =0.83