Study on a Novel Topology of a Double Two-phase Machine Drive System

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***Abstract*—A novel topology of a double two-phase machine drive system is proposed. It is shown that by connecting the neutral lines of a two-phase permanent magnet machine(TPPM) and a two-phase induction machine(TPIM), only four switches need to be used for each machine and the two machines share one set capacitors. This paper develops the mathematical model of this system and establishes the simulation model accordingly. Simulation results are given to demonstrate the feasibility of the concept. The results obtained in this paper shows that the novel double two-phase machine system has promising potential.**

***Keywords*—Topology, a two-phase machine, simulation.**

I. Introduction

With the continued improvement of power electronics and control technology, the scope for ac variable speed motor systems continues to widen. Recently, attention has moved to the study of machines with phases different than three. The main reason for interest in two phase motors is that such a motor is simple to control. Presently, researchers are addressing their attention towards variable speed drives with two-phase motors [1-5]. Most of these researchers focus on the conventional two-phase motors [3-5]. Namely, the motors include two windings—the main and auxiliary winding, characterized by different number of turns. Typically these so-called two-phase motors are supplied by a fixed single-phase supply, utilizing a permanent phase-split capacitor. At the same time, other researchers have addressed their attention towards symmetrical two-phase motors, which have two orthogonal identical windings [6-7]. In general, two-phase motors with or without the same number of turns per phase can be represented by Fig. 1 [1],[7].

At present both these two topologies are under investigation. Most researchers of two-phase inverters have selected the two-leg type as the model configuration [2],[7],[8]. Others have taken interest in a three-leg type topology [1],[9]. Considering cost, if a split capacitor is cheaper than a switch, then an inverter with a split capacitor will be less expensive. In fact, the inverter commonly used in three-phase motors has the same topology as Fig. 1(b). Some researchers use the structure of Fig. 1(a) replacing the conventional topology in inverter of three-phase motor, to reduce cost[10].

Thus far, no papers have treated the possibility of connecting a pair of two-phase motors to the same dc link. By connecting neutral points of a two-phase permanent magnet machine(TPPM) and a two-phase induction machine (TPIM), only a single center tapped link capacitor can be used to supply both motors. In this paper, dynamic performance of the novel topology will be analyzed and mathematical modeling will be given. Finally, the paper describes a method for simulation implementation and gives examples of simulation results.

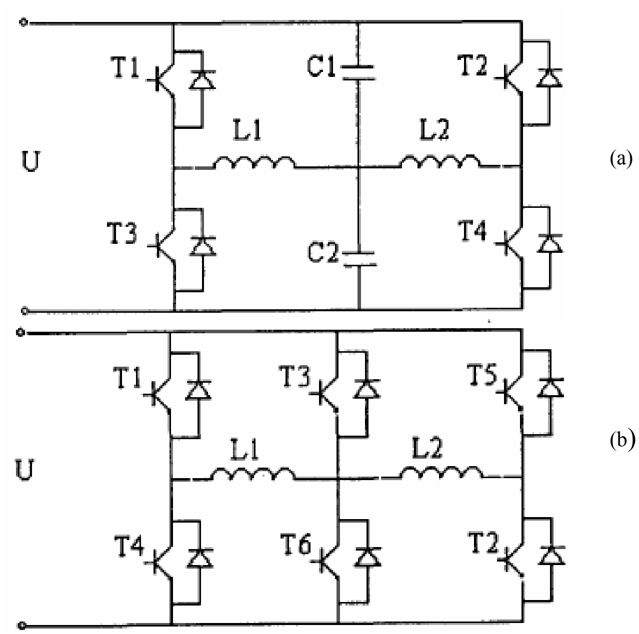


Fig.1: (a) Two-phase inverter with split capicitor in dc link

(b) Two-phase inverter with six switches

II. Mathematical Model of a double two-phase machine

In order to simplify the analysis, the following assumptions are made:

1) The surface of stator and rotor is smooth, so effect of slotting is ignored.
2) Saturation of the core and skin effect are ignored.
3) Windings of the two-phase machines are symmetrical, and harmonic components of air magnet field are ignored.
4) For a two-phase PM damp windings are transformed to

direct axis and quadrature axis.

5) Voltage U of dc link is a constant.

Fig. 2 shows the topology of the double two-phase machine drive system configuration. In Fig. 2, L1 and L2 are the stator windings of a two-phase PM machine, L3 and L4 are the stator windings of a two-phase IM. Detailed information concerning the windings is shown in Fig 3. Currents i_{A1} , i_{B1} and i_{A2} , i_{B2} in Fig. 3 are respectively i_{L1} , i_{L2} and i_{L3} , i_{L4} in fig.2.

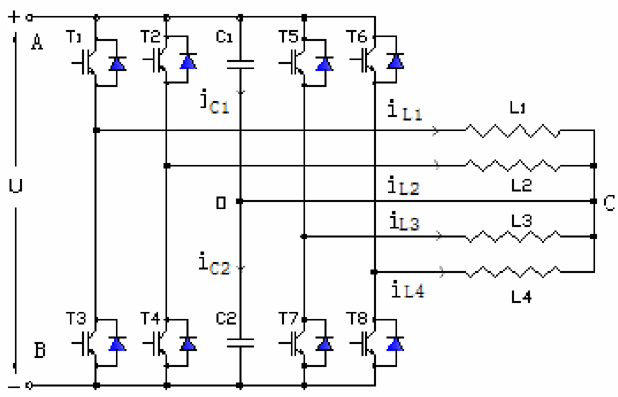


Fig.2 Topology of a DTPIM drive system

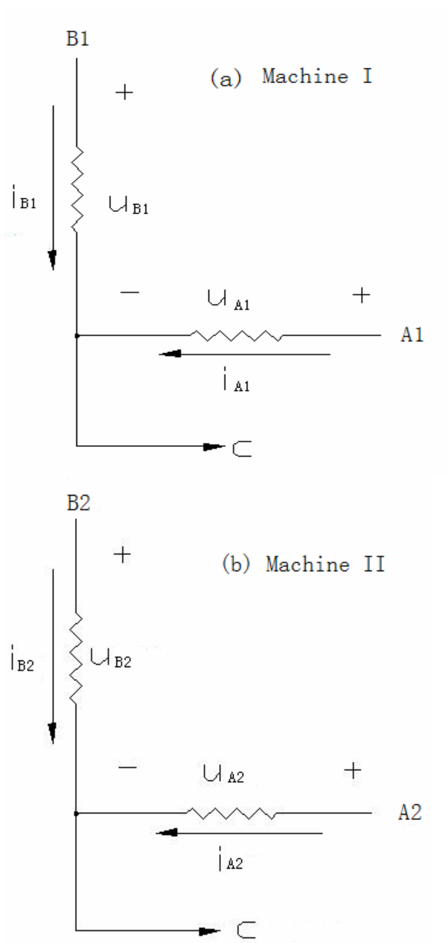


Fig. 3 Winding connecting diagram

For purposes of analysis assume now that the voltage at the two terminals of capacitors C_1 and C_2 is $U_{c1}(U_{AO})$ and $U_{c2}(U_{OB})$. The following equations describe the mathematical model of the split capacitors:

$$i_{A1}+i_{B1}+i_{A2}+i_{B2}+i_{C1}=i_{C2} \tag{1}$$

$$U=U_{C1}+U_{C2} \tag{2}$$

$$\begin{cases} pU_{C1}=\dfrac{1}{C_1}i_{C1} \\ pU_{C2}=\dfrac{1}{C_2}i_{C2} \end{cases} \tag{3}$$

From (2) and (3) ,considering U is a constant,(4) is got:

$$i_{C2}=-\frac{C_2}{C_1}i_{C1} \tag{4}$$

A Modeling of A TPPM

Fig. 4 is physical model of a TPPM. Two-phase stationary windings A and B are transformed to dq rotating reference frame. Permanent magnet is located in d axis. Rotating speed of dq reference frame is same as that of rotor. Seeing fig. 4 and fig. 3, mathematical model of a TPPM in dq rotating reference can be got by (5)-(7).

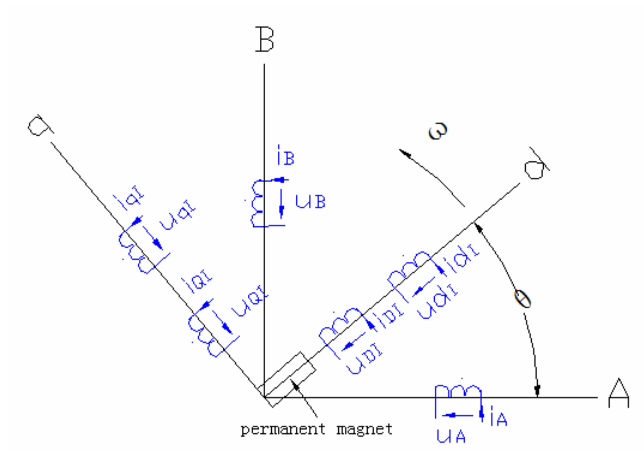


Fig.4 Physical model of a TPPM

(1) voltage equations

$$\begin{cases} u_d=R_s i_d+p\psi_d-\omega\psi_q \\ u_q=R_s i_q+p\psi_q+\omega\psi_d \\ 0=R_D i_D+p\psi_D \\ 0=R_Q i_Q+p\psi_Q \end{cases} \tag{5}$$

(2) flux linkage equations

$$\begin{cases} \psi_d=L_{sd}i_d+L_{md}i_D+\psi_f \\ \psi_q=L_{sq}i_q+L_{mq}i_Q \\ \psi_D=L_{md}i_d+L_{rD}i_D+\psi_f \\ \psi_Q=L_{mq}i_q+L_{rQ}i_Q \end{cases} \tag{6}$$

(3) Torque and motion equations

$$\begin{cases} T_e = n_p(\psi_d i_q - \psi_q i_d) \\ \quad = n_p(\psi_f i_q + (L_{sd} - L_{sq}) i_d i_q \\ \quad + (L_{md} i_D i_q - L_{mq} i_d i_Q)) \\ T_e = \dfrac{J}{n_p}\dfrac{d\omega}{dt} + T_L \\ \omega = p\theta \end{cases} \quad (7)$$

In（5）-（7）， physical meaning of main symbols is as follows:

L_{sd} —direct axis self inductance of equivalent two-phase stator windings， $L_{sd}= L_{ls}+L_{md}$；

L_{sq} —quadrature axis self inductance of equivalent two-phase stator windings， $L_{sq}= L_{ls}+L_{mq}$；

L_{md} — mutual inductance between stator winding and damp winding in direct axis；

L_{mq} —mutual inductance between stator winding and damp winding in quadrature axis；

L_{rD} —self inductance of direct axis damp windings， $L_{rD} = L_{lD} + L_{md}$；

L_{rQ} —self inductance of quadrature axis damp windings， $L_{rQ} = L_{lQ} + L_{mq}$；

L_{lD}、L_{lQ}—leakage inductance of direct axis and quadrature axis damp winding respectively.

ψ_f—flux linkage provided by permanent magnet

d、q、D、Q— as subscript they refer to direct axis and quadrature axis of stator windings and damp windings respectively.

θ —electrical degree which direct axis leads A phase winding .

ω—rotating speed of dq0 coordinates and rotor.

J—moment of inertia

B Modeling of A TPIM

Fig. 5 is physical model of a TPIM. The windings of squirrel cage rotor have already been transformed to stator windings side. Seeing fig. 5, mathematical model of the TPIM in stationary coordinates can be got by (8)-(10):

(1) voltage equations

$$\begin{cases} u_{s\alpha} = R_s i_{s\alpha} + p\Psi_{s\alpha} \\ u_{s\beta} = R_s i_{s\beta} + p\Psi_{s\beta} \\ 0 = R_r i_{r\alpha} + p\Psi_{r\alpha} + \omega\Psi_{r\beta} \\ 0 = R_r i_{r\beta} + p\Psi_{r\beta} - \omega\Psi_{r\alpha} \end{cases} \quad (8)$$

(2) flux linkage equations

$$\begin{cases} \psi_{s\alpha} = L_s i_{s\alpha} + L_m i_{r\alpha} \\ \psi_{s\beta} = L_s i_{s\beta} + L_m i_{r\beta} \\ \psi_{r\alpha} = L_m i_{s\alpha} + L_r i_{r\alpha} \\ \psi_{r\beta} = L_m i_{s\beta} + L_r i_{r\beta} \end{cases} \quad (9)$$

(3) Torque and motion equations

$$\begin{cases} T_e = n_p L_m (i_{s\beta} i_{r\alpha} - i_{s\alpha} i_{r\beta}) \\ T_e = T_L + \dfrac{J}{n_p}\dfrac{d\omega}{dt} \end{cases} \quad (10)$$

In（8）-（10）， physical meaning of main symbols is as follows:

L_s —self inductance of two-phase stator windings， $L_s= L_{ls}+L_m$；

L_r —self inductance of two-phase rotor windings， $L_r= L_{lr}+L_m$；

L_m — mutual inductance between stator winding and rotor winding in same axis；

s、r— as subscript they refer to stator and rotor respectively.

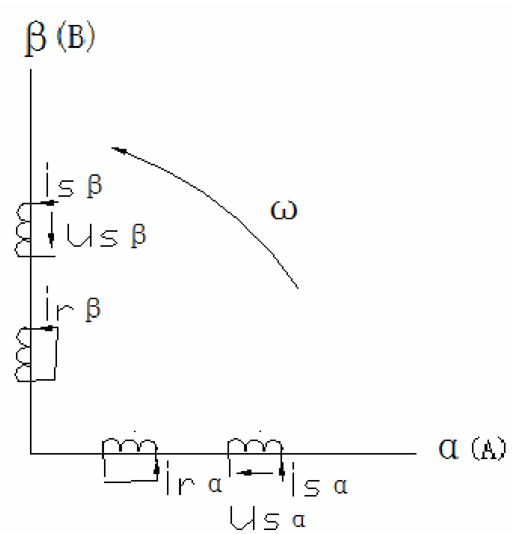


Fig.5 Physical model of a two-phase IM

III. SIMULATION MODEL

From (1)-(10), and Fig. 2, the simulation modeling of a double two-phase machine shown in Fig. 6 can be obtained. The simulation model consists of three subsystems. Two of them are a TPPM and a TPIM. The third part is the subsystem of calculating i_{C1}, i_{C2} and ripple voltage of split capacitors dU_{C1}, dU_{C2}, which are decided by (11).

$$\begin{cases} U_{C1} = U_{C10} + dU_{C1} \\ U_{C2} = U_{C20} + dU_{C2} \end{cases} \quad (11)$$

where U_{C10} and U_{C20} are the initial value of U_{C1} and U_{C2}, which are determined by (12).

$$\begin{cases} U_{C10} = \dfrac{C_2}{C_1 + C_2} U \\ U_{C20} = \dfrac{C_1}{C_1 + C_2} U \end{cases} \tag{12}$$

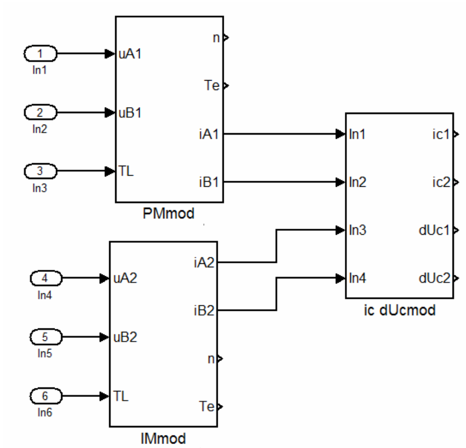


Fig.6 Simulation modeling of the double two-phase machines

IV. Simulation Example

For the purpose of establishing feasibility, a 1.1kW 4 pole machine drive system was investigated. The main parameters of the TPPM are: R_S=4.29Ω, R_D=R_Q=4.81Ω, L_{sd}=0.12175H, L_{sq}=0.44237H L_{md}=0.11113H, L_{mq}=0.43175H, L_{rD}=0.124H, L_{rQ}=0.44462H, J=0.01kg.m^2. And main parameters of the TPIM are: R_S=5.0Ω, R_r=3.0Ω, L_S=0.33627H, L_r=0.3456H L_m=0.322H, J=0.01kg.m^2. Both rated phase voltages are 220V, rated frequencies are 50Hz and C1=C2=3300μ F.

A. Simulation Results of A Double Two-phase Machine System Supplied By An Ideal Sinusoidal Voltage Source

For the TPPM, no load starting while the load is added to 7N.m after 0.5 seconds. For the TPIM, a 3N.m is added during starting while a 7N.m is added after 0.5seconds. Fig. 7 gives the simulation results of the system supplied by sinusoidal wave voltage. Fig. 7(e) and 7(f) are the simulation results when the capacitor is changed from 3300μ F to 1500μ F.

Fig. 8 gives the simulation results when the frequency of the TPPM is changed to 40 Hz, with a corresponding voltage changed to 176 V.

B. Simulation Results of A Double Two-phase Machine System Supplied By Square Wave Voltage Source

Figure 9 are the simulation results of the double two-phase machine system supplied by square wave voltage.

C. Simulation Results Analysis

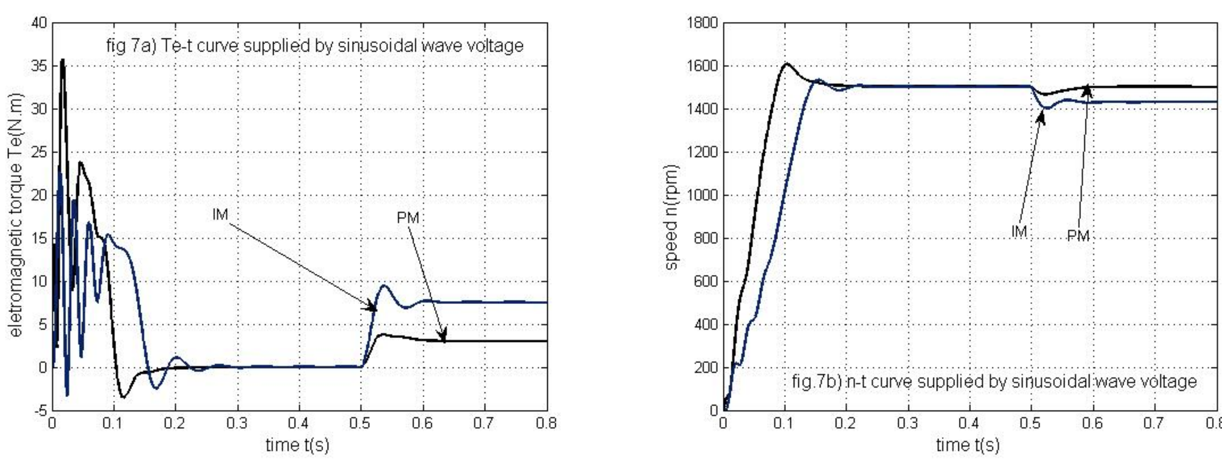
Compared simulation results in different condition, we follow:

1) If two machines run at same time and their load is closer, then the currents that flow through capacitors is smaller. The ripple voltage of capacitor is smaller also (see fig. 7(c)-(f));

2) When capacitor becomes larger, the ripple voltage of capacitor becomes smaller, but the current that flows through capacitor keeps same(see fig. 7(c)-(f));

3) When the frequency of two machines is not same, both current and ripple voltage of capacitor are not sinusoidal variables (see fig. 8(a)-(b));

4) The time to reach a stable state is longer when the double two-phase machine system is supplied by square wave voltage. On the other hand the speed ripple and electromagnetic torque ripple are greater.



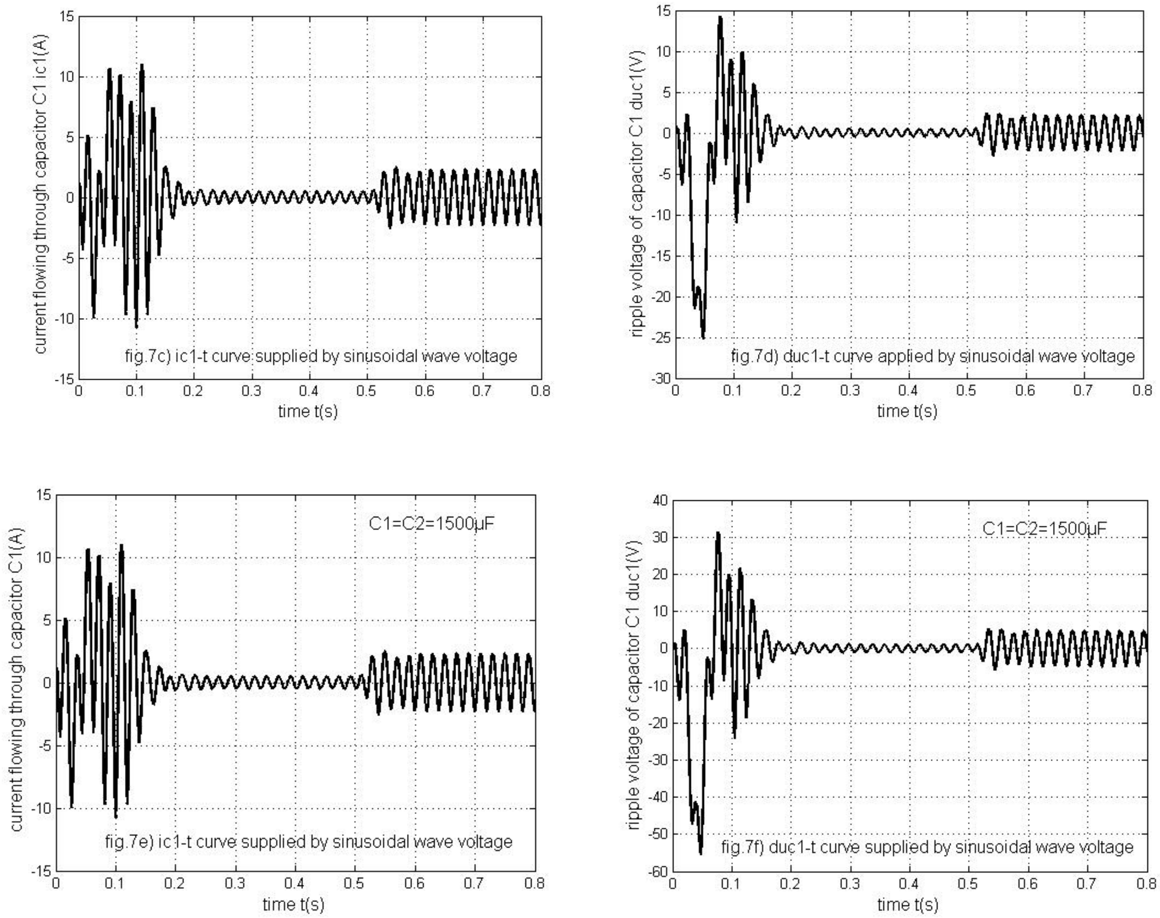


Fig. 7 Simulation results when motors are supplied by a sinusoidal wave voltage (frequency is 50Hz)

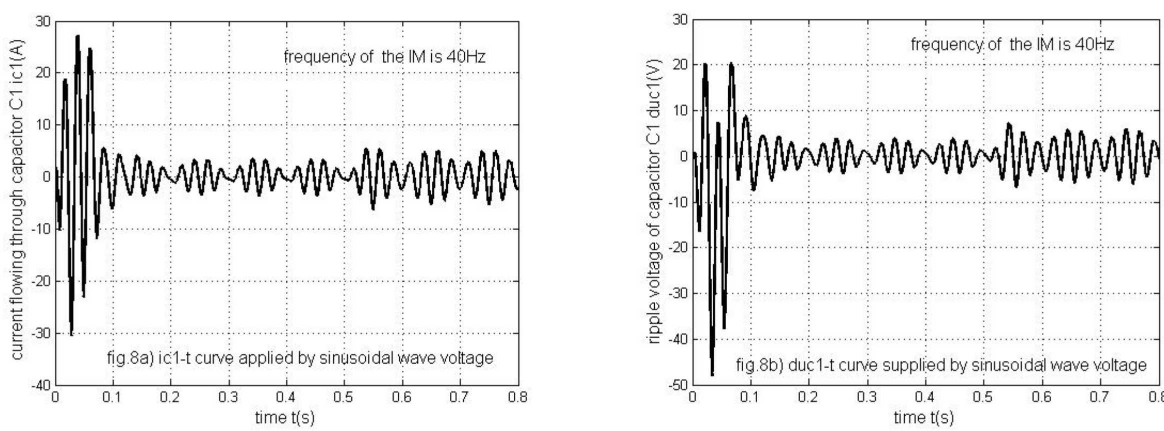


Fig. 8 Simulation results supplied by sinusoidal wave voltage (frequency of TPIM is 40Hz)

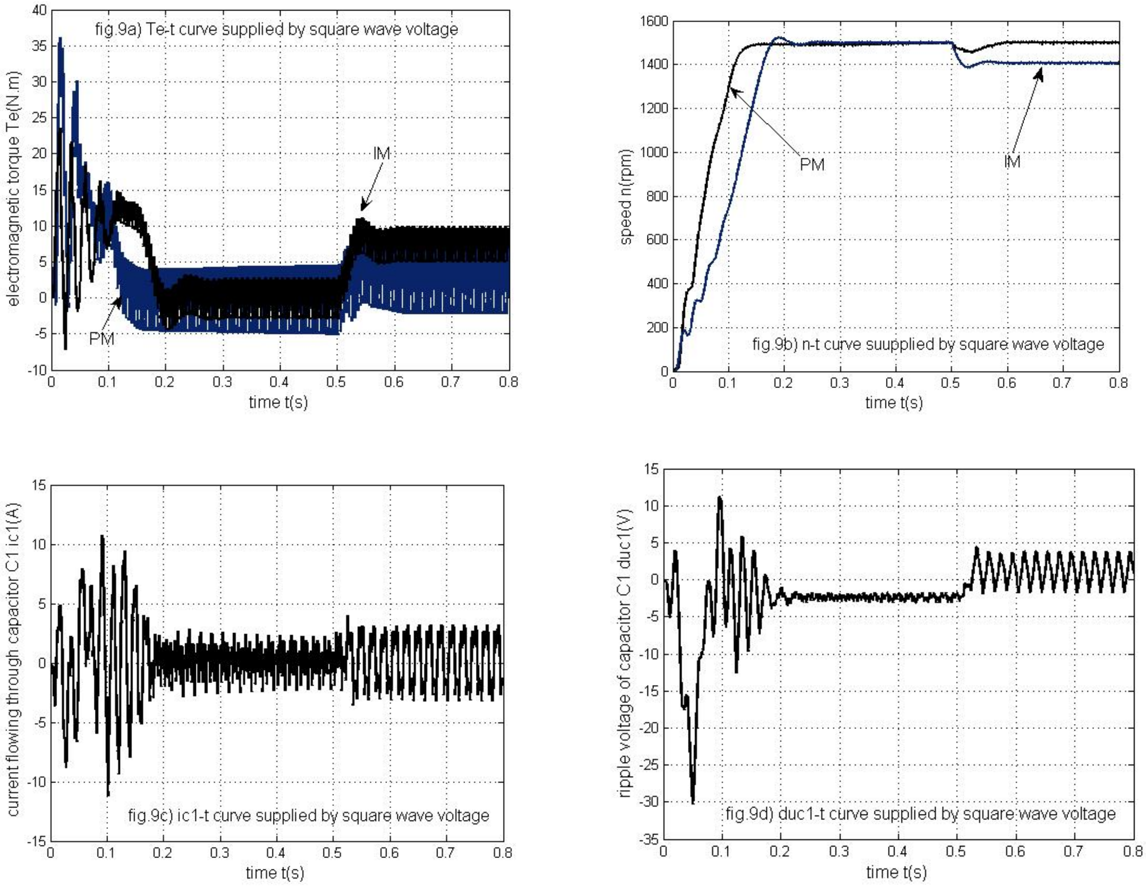


Fig.9 Simulation results supplied by square wave voltage

V. Conclusion

This paper sets forth a two-phase permanent motor and induction motor drive system. It develops the mathematical model and establishes the simulation modeling accordingly. Simulation results match theory analysis. This new drive set can reduce switch number when supplied by inverter when two motors are used for an industrial process. Simulation results show the system works well. It may used in some fields where the distance between the two machine is close, such as textile machines, synthetic fiber machines.

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