Implementation and Verification of 50kW Propulsion System in Electric Vans

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Abstract

In this paper, a 50kW and high efficiency propulsion system is implemented and verified for an electric van (E-Van). Not only high power, high efficiency, and high power density are necessary, but also system reliability and durability are very important. In order to obtain the goals, robust control strategy and high efficiency power module are necessary to be considered. Especially, robust current control in overall operation range can enhance system reliability and high efficiency power module can reduce the energy consumption, respectively. Complete experiments by a dynamometer including torque-speed map, efficiency map, environmental and duration tests, are implemented. The established torque-speed map provides a good calibration reference. Finally, the proposed 50kW propulsion system is mounted on a van and a duration test in road is verified.

Keywords: high power, high efficiency, motor, current control, durability

1 Introduction

Saving energy issues are paid more attention in recent years. Especially, green vehicles are the most important research topics [1-2]. For this reason, Industrial Technology Research Institute (ITRI) in Taiwan has developed from internal-combustion engine, hybrid system, to electric vehicle for many years. ITRI keeps developing the target of zero emission vehicles. The goal is to achieve high power, high efficiency, high power density electric propulsion system with verification of environmental and duration tests, etc.

The paper presents a high power propulsion system including motor and controller in an E-Van. There are three parts in this paper. Section 2 presents a robust current control for torque control in dynamic load of vehicle [3]. The sliding mode controllers achieve robust current control of d-q axes in overall operation range. Thus, occurrence of over current can be diminished and system stability and reliability can also be enhanced. Further, the third harmonic injection with sinusoid PWM is used [4-5]. The advantage is to reduce computation complexity of a motor controller. Simple computation can provide PWM signals. Therefore, it can raise both rates of program execution and voltage utility. Finally, the proposed control technology in this research is implemented with a digital signal processor (DSP) F2808, which is produced by Texas Instruments.

Section 3 presents experimental results by a dynamometer. The experiments include torque-speed map, efficiency map, power curves, generation map, and duration tests. Complete experiments guarantee stability and reliability of the propulsion system. Section 4 presents environmental tests. The developed electric propulsion system is verified by IP degree against dust and liquid, etc. Experimental results guarantee that the developed 50kW propulsion system is qualified to drive a van. In the Section 5, the vehicle verification is based upon a van with 1348kg. Since the wide speed range, single gear ratio can be used. Related vehicle tests are implemented, including energy consumption by UDDS cycles, duration, acceleration, and climbing capability. Finally, Section 6 gives conclusion.

2 Architecture of PM motor control strategy

In this paper, a 50kW Permanent Magnetic (PM) motor is considered to be the propulsion system of electric vehicle since the PM motor is higher average efficiency and higher power density than the Induction Motor (IM). Therefore, the 50kW PM motor is very suitable for the E-Van. Generally, PM motor is driven by sinusoid vector control. It can drive PM motor with higher efficiency than square wave control. Therefore, sinusoid vector control is widely used in PM motor control for electric vehicles.

In order to simplify analysis complexity, 3-phase AC motor is usually transferred to be a stationary d-q axes model ($d^s - q^s$ frame). Transforming stationary d-q axes model to synchronous rotating d-q axes model ($d^e - q^e$ frame) is a standard process. Thus, the motor torque is directly proportional to the q axis stator current. For vector control of PM motor, the current vector has to be set on the q axis, i.e., there is no stator current on the d axis. In other words, the motor torque can vary linearly to the q axis current compoment. The control method is similar to drive a DC motor. Fig. 1 shows the block diagram of motor control algorithm. The control block diagram includes current feedback, current control (torque control), frame transformation system, 3rd harmonic injection, sinusoidal PWM generator, and position/speed sensor.

Generally, PI controller is very popular in motor current control. It is very easy to be implemented. Suitable PI gains can be easy decided by numerical simulation or control theory. Especially, it is very useful for industrial IM motors since operation speed range and environment is fixed. However, electrical parameters of PM motor in most situations vary with temperature or operation condition and wide speed range is necessary in electrical vehicles. Therefore, fixed PI control gains are not suitable enough to handle the control system. Different PI control gains in different operation range are needed but it causes hard work for trial and error.

In this section, sliding mode control is used to replace the PI controller. It is widely used for robust control. The most advantages of sliding mode control are robust against external disturbances and parametric variation [3]. In other words, robust current control can reduce probability of over current and protect hardware. Moreover, good current control also can raise system efficiency. Although sliding mode control has more complex in computation than a PI controller. However, most microcontrollers are qualified enough in nowadays. Moreover, 3rd harmonic injection and sinusoidal PWM generator are also used in this paper. Simple computation can provide PWM signals to drive the PM motor. Therefore, it can raise both rates of program execution and voltage utility. In next section, experimental results in a dynamometer demonstrate the validity and effectiveness of the control algorithm.

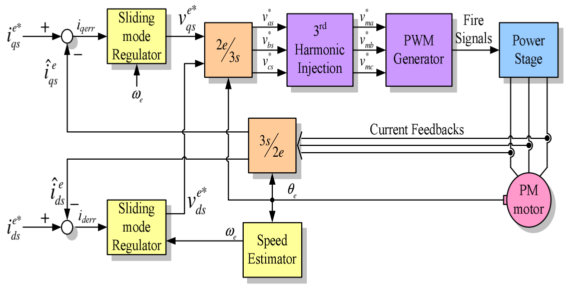

Figure 1: Block diagram for PM motor control

3 Experimental results

Fig. 2 and Fig. 3 show the motor controller and 50kW motor, respectively.

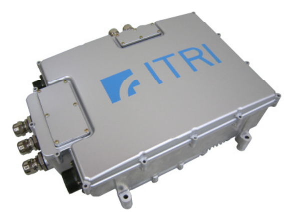

Figure 2: 50kW motor controller

Figure 3: 50kW PM motor

Through a dynamometer test in a laboratory, the 50kW electrical propulsion system shows performance in Fig. 4 to Fig. 6. The experimental results of Torque-Speed curves in Fig. 4 confirm that the maximum output torque is 220 N.m @ <3000rpm. Large torque in low speed is characteristic. It is very obvious that wide speed range is presented by good flux-weakening capability. Maximum speed is over 8000rpm. Fig. 5 shows the input, output power, and efficiency curves, respectively. The maximum output power is 70kW @ 3000rpm. Then the power density is 1.4 kW/kg. Efficiency map is shown in Fig. 6. It is obvious that maximum system efficiency is 92% @ 3000rpm and almost all efficiency ranges are above 80%. According to the experimental results, good driving performance of the proposed electrical propulsion system is verified.

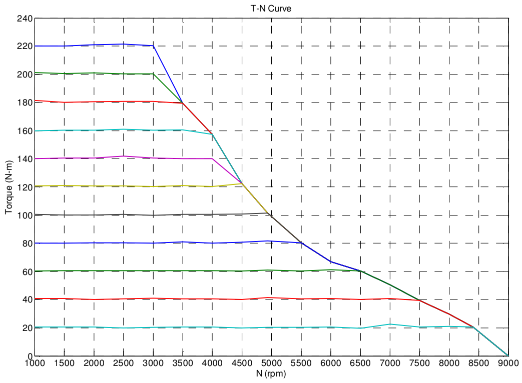

Figure 4: Torque-Speed curves

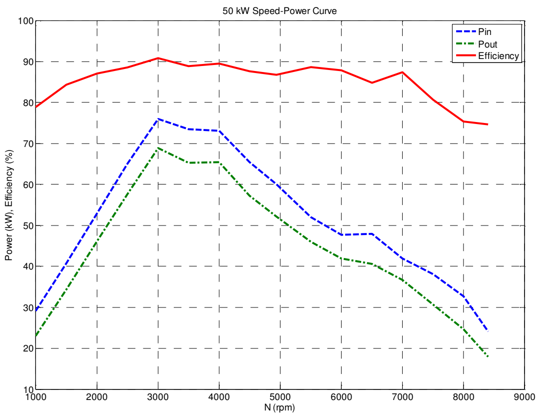

Figure 5: Power curves

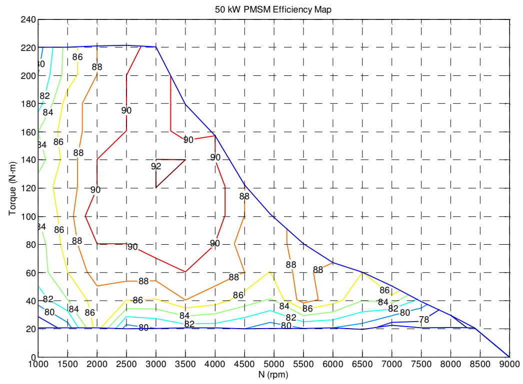

Figure 6: Efficiency map

Table 1 shows the re-generation current table which indicates the amplitude of re-generation current of DC-Link. According different torque commend at different motor speed, the PM motor can provide re-generation current back to battery. The amplitude of re-generation current decides breaking torque. Larger current causes larger breaking torque. The table is a very good reference for a vehicle control unit (VCU) to develop a smooth break re-generation strategy.

Table 1: Re-generation current table (unit: A)

Motor Speed (rpm) / Torque Command (Nm)	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000
0	0	0	0	0	0	0	0	0	112.4	121.1	130.3
10	4.05	5.64	7.17	8.45	10.24	11.55	13.67	15.16	112.4	121.1	130.3
20	8.59	11.8	14.23	16.51	20.01	23.26	27.4	30.5	112.4	121.1	130.3
30	14.45	18.76	21.9	26.1	30.6	35.3	40.9	45.4	112.4	121.1	130.3
40	18.69	25.6	30.7	34.8	40.8	46.8	54.2	60.4	112.4	121.1	130.3
50	18.69	31.5	39.6	43.9	50.8	58.6	67.6	75.1	112.4	121.1	130.3
60	18.69	37.4	48.7	53.1	61	70.2	80.8	90	112.4	121.1	130.3
70	18.69	44.1	56.5	62.1	71.1	81.7	94.2	104.7	114.2	121.1	130.3
80	18.69	49.4	64.5	70.8	81.2	93.4	107.5	116.4	124.4	131.8	N/A
90	18.69	49.4	73.1	80.5	91.6	105.6	117.7	126.1	N/A	N/A	N/A
100	18.69	49.4	81.8	90.6	102.5	115.9	126.8	N/A	N/A	N/A	N/A
110	18.69	49.4	86.6	101.1	113.4	124.5	N/A	N/A	N/A	N/A	N/A
120	18.69	49.4	86.6	113.3	122.6	133.8	N/A	N/A	N/A	N/A	N/A
130	18.69	49.4	86.6	114.6	134.6	N/A	N/A	N/A	N/A	N/A	N/A

4 Environmental test

In the environmental test, there are three parts as follows.

- Duration test in a dynamometer (Rules in ITRI)
- Against liquid test (IEC 60529 IPX5)
- Against dust test (IEC 60529 IP5X)

Since the duration test is no standard and criteria so far, the duration test rules are defined by ITRI in Taiwan. As shown in Table 2, a 2-hours testing cycle is defined for duration test. Therefore, there are 50 cycles in 100 hours duration.

Table 2: Testing cycle for 100-hours iteration duration

Phase	Speed (rpm)	Output power	time

1	2500	Rated power	29m10s
2	3000	Rated power	29m10s
3	3500	Rated power	29m10s
4	4000	Rated power	29m10s
5	2500	Maximum power	20s

After 100-hours iteration test, Fig. 7 to Fig. 8 show results of the final 10 times iteration test. It is obvious that there are no deteriorated motor torque, motor power, and motor efficiency at same control command.

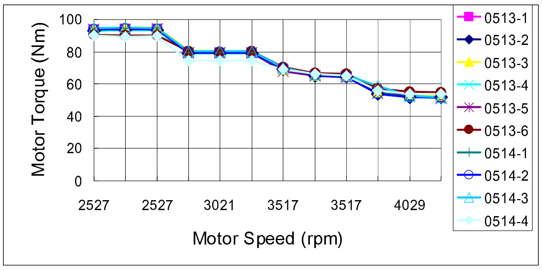

Figure 7: Motor torque in 100-hours duration

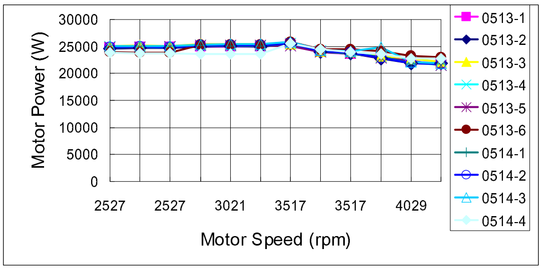

Figure 8: Motor power in 100-hours duration

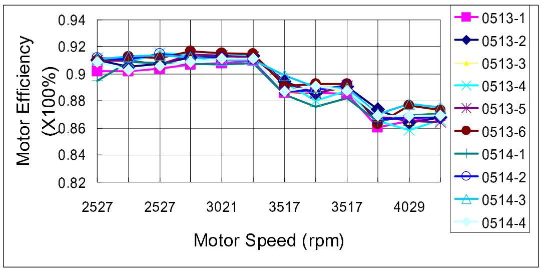

Figure 9: Motor efficiency in 100-hours duration

A test against water (IEC 60529 IPX5) is verified. The test is very important, especially for vehicle application. The test degree IPX5 means there is no damage in the motor and controller for spraying of water from any directions. Define test conditions as follows.

- Status: No power
- Spraying volume：12.5 liter/minute
- Spraying distance: 2.5 meter
- Spraying direction: Front, back, left, right, button, and top.
- Test time：One side for one minute and total is 6 minutes.

Another test against dust (IEC 60529 IP5X) is verified. The test degree IP5X means there is no damage in operation or safety for invading dust. Define test conditions as follows.

- Status: No power
- Dust material：100% dry fine
- Dust size: <40μm(diameter)
- Dust density：2.03 g/cm^3
- Chamber volume: 2 kg/m^3
- Spraying direction：Vertical to tested thing, from up to down.
- Test time：2 hours

Finally, the test results against dust and liquid show that the developed electrical propulsion system passes IP55.

5 Performance test of E-Van

According to Section 3, the experimental results guarantee that the developed 50kW propulsion system satisfies requirements of driving an E-Van. Fig. 7 shows a photograph of the electric van. The vehicle weigh is 1348kg. By CAN bus communication, the vehicle control unit can handle all sub-systems in the E-Van, including a battery management system, a charging system, and a motor control system. For the 50kW electric propulsion system in the E-Van, main missions are to receive torque command from the VCU and to transmit protection codes to VCU. In performance test of E-Van, it includes three parts as follows.

- Motor Speed of UDDS
- Acceleration and maximum speed test
- Climbing test
- Road test

Setting resistance coefficients areμ_0=0.008 ， Cd=0.350.

Figure 7: Photograph of the electric van

In energy consumption test, vehicle weight is set as 1546kg, driving pattern of energy consumption is 1372 seconds and 12km as shown in Fig. 8. It shows variation of energy consumption @ driving pattern. According to vehicle speed, voltage, current, and distance, etc, energy consumption can be calculated. Test results are 173 Wh/km and cruising distance 100km. Fig. 9 shows the corresponding motor speed of UDDS.

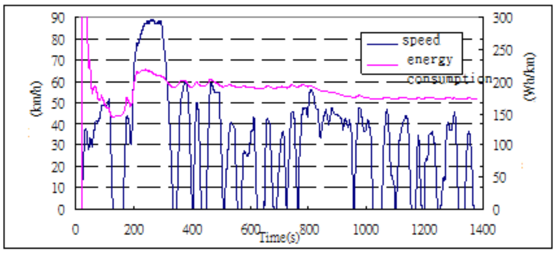

Figure 8: Variation of energy consumption @ driving pattern

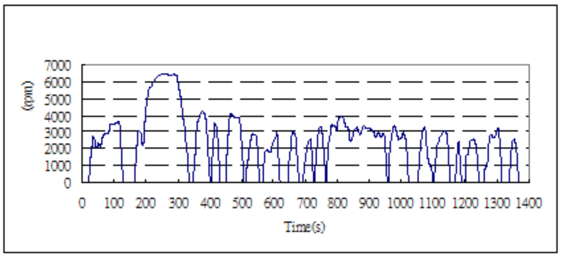

Figure 9: Motor speed of UDDS

In acceleration test, vehicle weight is set as 1630kg. The test method is that full pedal until speed is not rising. Test results are maximum speed 100km/hr @ 7200rpm and acceleration 0~60km/hr @ 9 sec. In climbing test, vehicle dynamometer is set as 25% slope@50% full load (resistance: 4156 N). In Fig. 10, it is obvious that vehicle speed from 27km/hr down to 10km/hr when resistance is increased to 4156 N. That means the E-Van is with the climbing capability of 25% slope@50% full load. At the same time, climbing motor speed is 715rpm as shown in Fig. 11 and battery current is 71A, respectively.

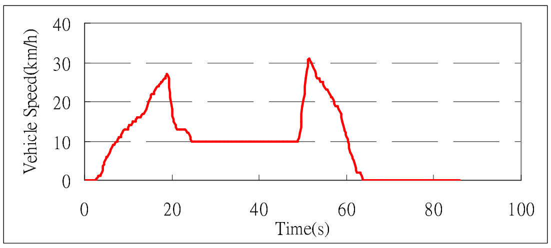

Figure 10: Vehicle speed of climbing

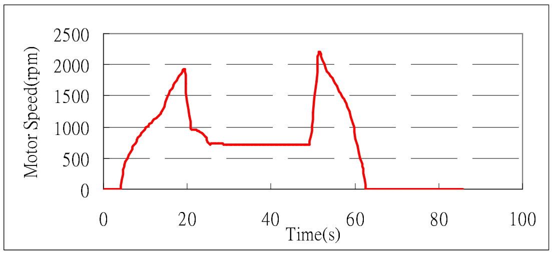

Figure 11: Motor speed of climbing

In road tests, there are two pars, including duration test and road slope test. So far, the E-Van has completed 6000km road test and 1600km hard road test. Comparison of vehicle performance after duration test, including acceleration, climbing capability and maximum speed is not deteriorated. In road slope test, the E-van of full load 1850kg can climb 12%, 18%, and 20% test roads with vehicle speed 1.71 sec, 1.70 sec, and 1.83 sec for 10m distance, respectively.

6 Conclusion

This paper presents implementation and verification of 50kW propulsion system in electric Vans. Not only control strategies are considered, but also environmental tests, duration test, performance test in dynamometer, and road test are all verified. The experimental results show that the maximum power is above 50kW @ 2500 rpm~5000rpm, maximum torque is 210N.m @ < 3000rpm, maximum system efficiency is 92%, and maximum speed is above 8000rpm. All tests guarantee that the developed electrical propulsion system is qualified enough to achieve performance target of an E-Van. Additionally, environmental tests further show that good stability and reliability can be achieved.

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