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Development of a Software Platform for Taiwan's Electric Van

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Abstract

The main purpose of this paper is to conduct the critical technologies and design procedures of a versatile software platform for Taiwan's electric vans established by Industrial Technology Research Institute (ITRI), Taiwan. To raise the development efficiency and to reduce the cost, a Matlab/Simulink-coded software, named "E-Van-Sim", was designed for the purpose of evaluating the vehicle/subsystem performance and for preliminarily studying prototype vehicle control strategies. By adopting forward/backward simulation approach, E-Van-Sim is able to accommodate both the real-time simulation and the high model accuracy. It consists of subsystems (key components) such as the traction motors, lithium batteries, high-power transformers (DC/DC converter, charger, etc.), auxiliary components, transmission, and longitudinal vehicle dynamics. The modules of drive behaviour, standard testing cycles and vehicle control strategy were also integrated. This study demonstrates the results of vehicle/subsystem dynamics, energy consumption and energy recovery, and vehicle control rules (operation modes) under specific driving cycles. It proves that the effective research is accessible by using the developed E-Van-Sim. An on-line version of E-Van-Sim will be established in order to complete the Hardware-in-the-Loop (HIL) platform in the near future.

Keywords: electric vehicle, software, vehicle control strategy, technology development.

1 Introduction

Being the most famous and outstanding automotive research organization in Taiwan, Industrial Technology Research Institute (ITRI) has produced various types of green vehicles and key components for the past years as shown in Figure 1. Advanced technologies for green power/energy modules, (hybrid) electric vehicles and control units have been successfully developed and promoted to Taiwan's automotive industry for the past decades. According to Taiwan government policies, pure electric vehicles have become the mainstream that fit the goals of concepts of "clean zone" and the "low carbon city" [1]. Postal vans, which are characterized by fixed cruising route and short traveling distance, are suitable for being powered by high-energy-density batteries. To evaluate the performance of its key components

also to modify the control strategies in the vehicle control unit (VCU), a simulation platform is needed prior to the real vehicle implementation. Hence, many commercial vehicle simulation packages such as ADVISOR [2] and PSAT [3] have been developed for the past few years. By selecting subsystem specifications and vehicle configurations, the output performance (acceleration, cruising mileage, energy consumption) can be evaluated via the backward simulation method. Such simulation tools are suitable for system designs. However, for the vehicle control strategies, the transient dynamics of vehicle/subsystems is required and the forward simulation must be employed [4]. Hence, this paper accommodates the function of system designs (backward simulation) and control strategy development (forward simulation) via the backward/forward simulation approach.
This paper is organized as follows. In Section 2, the configuration, specification and the core technologies of the E-Van will be briefly introduced. Section 3 constructs the dynamic behaviour (state equations) of all subsystems (motor, battery, transmission, etc.). Section 4 demonstrates the simulation results of E-Van-Sim, and finally the conclusion in Section 5.

Figure 1: Development of Green Vehicles in ITRI

2 ITRI E-Van Technology

Figure 2 illustrates the ITRI E-Van technology, and Table 1 summarizes the specification of all subsystems. The gross weight of the vehicle is 1850 kg, where the rear wheels are propelled by a traction motor. In this vehicle, key components were majorly developed by ITRI. For the motor system, it is a 50kW permanent magnetic synchronous motor (PMSM) with a highest efficiency of 90+%. The peak power is 50kW, while the peak torque is 210 N-m. The motor control unit (MCU) consists of the IGBT power circuits and the programmable microchip with downloaded control strategies. Performance tests (efficiency T-N maps of charge and discharge, flux-weakening control, etc.) of the 50kW motor integrated with the MCU were implemented on the motor dynamometers. The traction torque and rotational speed are modified by a fixed-gear ratio transmission system to drive the rear wheels. The overall reduction ratio is 6.85.

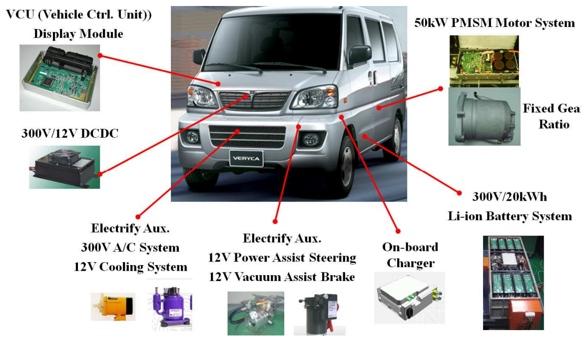

Figure 2: Technologies of E-Van in ITRI

Table 1: Specification of the ITRI E-Van

Item			Target
Vehicle	Dimension	LxWxH(mm)	4090x1570x1950
		Wheel Base(mm)	2610
		Wheel Drive	2WD Rear Drive
	Weight	Curb (kg)	≦1350
		Gross(kg)	1850
Propulsion	Motor	Type	PMSM
		Peak Power(kW)	50
		Peak Torque(Nm)	210
	Battery	Type	LI-Iron
		Capacity(Ah)	≧75
		Available Energy kWh	20
		Nominal Voltage	306.6 Volt
	T/M	Type	Single Speed/Fixed Ratio
		Reduction Ratio	1.274
		Wheel Axle Ratio	5.375
		Driveline Ratio	6.85
DC-DC		190~400 VDC	1000 w
Charger		AC110V/220 V	6.6 kW

For the energy sources, ITRI developed a 300V/20kWh lithium-ion battery packages and its battery management system (BMS). The electric capacity is 75Ah, while the stored energy is 20 kWh. The 300V battery package was developed by integrating battery modules in parallel/series. An ITRI battery module consists of 6 commercial battery cells in series with a supervisory control unit – module management unit (MMU). The MMU retrieves the data of cell temperatures and cell voltages sent by sensors. All MMUs are interconnected with the BMS by Control Area Network (CAN) system. The battery status thus can be analyzed online. The state-of-charge (SOC) of the battery can be evaluated judged by the voltage/current variation. The BMS also supervises each module and provides suitable control strategies to MMUs.

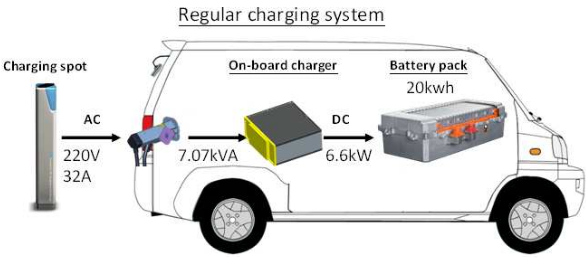

Figure 3: Charging System with On-Board Charger

To charge the E-Van, an AC110V/220 V on-board charger provides electricity with maximized 3.3kW power. To continuously provide sufficient power to the auxiliaries, a 300V/12V-1000W DC/DC converter was mounted so that the 300V high power battery can charge the 12V battery. Figure 3 exhibits the ITRI-made charging facility and the on-board charger. The fast charging station provides 7.07kVA power to the 6.6kW on-board charger, then to the battery package. For the self-developed auxiliaries, they include the A/C system, the cooling system, the power assist steering system and the vacuum assist brake system.

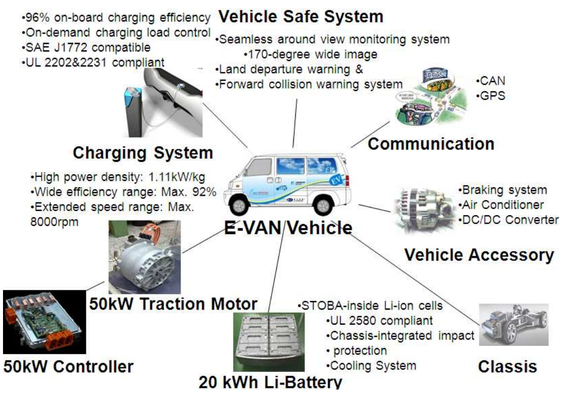

Figure 4: Technology Highlights of ITRI E-VAN

The technology highlights are further exhibited in Figure 4. To standardize the key technologies of ITRI subsystems, test protocols such as SAE J1772 and UL 2231 for on-board charger were utilized. The UL 2580 was employed for battery packages as well. The vehicle safety system was also integrated in the E-Van including the lane departure warning, forward collision warning system, etc.. Also, vehicle telematics and the information module (like: GPS, CAN communication) were included.

The core of the vehicle is the vehicle control unit (VCU). It contains the hardware and software segments. For the hardware, a microchip takes charge of the signal type transformation and the calculation of control strategy. The electric circuits on the mainboard provide the VCU protection and the signal processing. For the input/output ports, the analogy I/O, the digital I/O, the CAN module and the RS-485/232 port are interconnected to other control units, sensors and actuators. The configuration of the VCU software combined with the vehicle simulator is demonstrated in Figure 5.

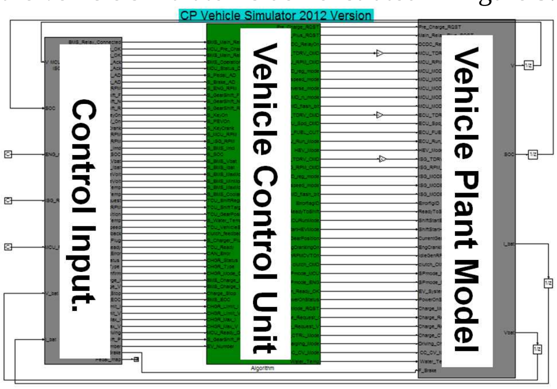

Figure 5: VCU/ software configuration

It is coded on the Matlab/Simulink platform and is separated in three parts. The first part is the control input, which receives the data from subsystem control units (subsystem information), from the driver (pedal, brake and gear-shift commands) and from sensors. The data will be sent to the vehicle control unit block as shown in Figure 6. Various multi-dimensional tables and quasi-empirical formulas are established in the left-hand side block. For instance, the 0-1000 digital pedal signal will be transferred to 0-100% pedal command. The modified signal will then be delivered to the middle block – operation modes. The modes are switched according to the input signals and subsystem status. Modes includes: system ready, key on, driving, regenerative braking, and coast down, etc.. Each mode has different control strategies and energy management policy. The right-hand side block regulates the torque ramp of the motor per sampling time to ensure the comfort driving.

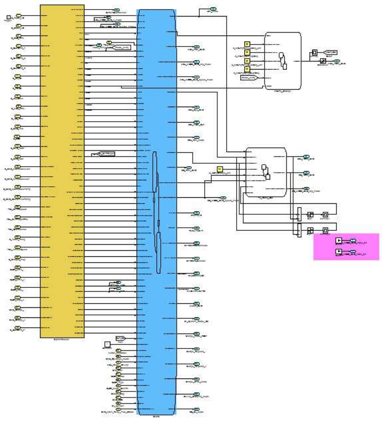

Figure 6: VCU Control Strategy

From above, it shows that ITRI has the capability to produce the prototype E-VAN with self-produced subsystems and control units. However, to shorten the R&D period, to raise the development efficiency and to reduce the cost and resources, the E-VAN simulator is needed for the preliminary study before the real tests.

3 ITRI E-VAN System Dynamics

The E-VAN-Sim was built in the Matlab/Simulink platform which is widely applied for various industrial fields [5]. Dynamics of subsystem of ITRI E-VAN combined with the VCU control strategies were coded separately in the Simulink block set. Each block is detailed as follows:

(1)Driving patterns: in this block, the route for daily driving can be selected. The ECE40 driving cycle was frequently selected to evaluate the vehicle performance and controls. A $2 \times n$ matrix was constructed (2 for time and velocity, n means n time steps). With this block, standardized evaluation of system performance and energy management can be managed.

(2)Driver's behavior: here, a PID controller was employed as the human action on the pedal and the brake (CMD) from the error of vehicle speed and the actual speed at each sampling time. The equation is given by:

$$CMD(\%) = Pe_v + D\frac{de_v}{dt} + I\int e_v dt \quad (1)$$

$$e_v = V_a - V_d \quad (2)$$

where e_v, V_a, V_d, P, I, D represent vehicle speed error, actual vehicle speed, demanded speed, P gain, D gain and I gain of the driver model.

(3)Traction motor: the traction torque (T_m) and rotational speed (ω_m) of the motor are two inputs for calculating the motor efficiency (η_m). The performance map was measured by the dynamometer and illustrated in Figure 7. The required power (P_m), drawn current (I_m) from the battery were also calculated. Associated equations are:

$$\eta_m(k) = f(T_m(k), \omega_m(k)) \quad (3)$$

$$I_m = T_m \cdot \omega_m / (\eta_m \cdot V_m) = P_m / (\eta_m \cdot V_m) \quad (4)$$

where V_m is the input DC voltage of the motor.

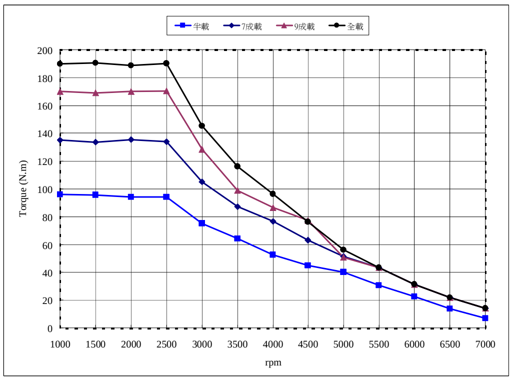

Figure 7: Motor Performance Test on the Dynamometer

(4)High-voltage lithium battery set: by using the resistance model, a first-order dynamics characterizes the system by an equivalent internal resistance (R_{int}) and a capacitor (C). In the battery circuit, an open circuit voltage (V_{oc}) is in series with R_{int}. With charging or discharging condition, the values of R_{int} and V_{oc} are different and can be interpolated by a set of 1-D tables. The battery current (I_{bat}) and the battery state-of-charge (SOC_{bat}) are determined by [6]:

$$I_{bat} = \frac{V_{oc} - \sqrt{V_{oc}^2 - 4P_{bat} \cdot R_{bat}}}{2R_{int}} \quad (5)$$

$$SOC_{bat}(k+1) = SOC_{bat}(k) + \frac{I_{bat}\Delta t}{C \times 3600} \quad (6)$$

. where Δt is the sampling time period, C is the maximum value of the electric capacity of the battery, while V_{oc} represents the open-circuit voltage.

(5)Integrated starter generator (ISG): similar to traction motor, the ISG torque (T_{isg}) and speed (ω_{isg}) are inputs to the efficiency contour measured by the motor dynamometer to calculate the ISG efficiency (η_{isg}), also to determine the needed charging power, charging current (I_{isg}) to the battery:

$$\eta_{isg}(k) = g(T_{isg}(k), \omega_{isg}(k)) \quad (7)$$

$$I_{isg} = T_{isg} \cdot \omega_{isg} \cdot \eta_{isg} / V_{isg} = P_{isg} \cdot \eta_{isg} / V_{isg} \quad (8)$$

where V_{isg} is the input DC voltage of the ISG.

(6)Transmission system: in this study, the transmission type is a fixed-gear manual transmission, which modifies the output torque (T_{GR}) and speed (ω_{GR}) from the motor to propel the vehicle. The real vehicle has P, N, D gear position. Here, for the position D, the gear ratio (GR) modifies the output torque and speed:

$$T_{GR} = T_m \cdot GR \quad (9)$$

$$\omega_{GR} = \omega_m / GR \quad (10)$$

(7)Longitudinal vehicle dynamics: the output torque of Eq. (9) on the wheel and the road load torque are two main forces that determine the acceleration or deceleration of a vehicle. The relationships between these forces are list below:

$$m_{veh} \frac{dV}{dt} = F_w - F_a - F_r - F_{c\lim b} \quad (6)$$

$$F_w = T_{GR} \times RR_{fin} / R_w \quad (7)$$

where m_{veh} is the vehicle mass; F_w, F_a, F_r, $F_{c\lim b}$ represent the traction force, the air resistance, the rolling resistance, the climbing resistance, respectively; RR_{fin}, R_w denote reduction ratio of the final drive, and the wheel radius.

(8)VCU Control Strategy: as Figure 5 and Figure 6 shown, the control strategies are developed by simulink/stateflow tool and are interconnected with the vehicle model by several junctions and transition lines.

By properly integrating above eight blocks, the E-VAN-Sim can be established. The structure of the program is demonstrated in Figure 8.

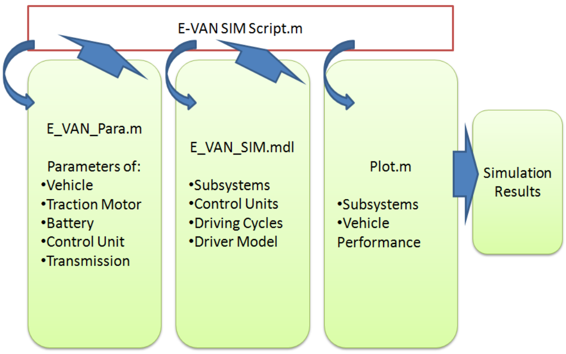

Figure 8: E-VAN-Sim Program Structure

A script file (script.m) was coded to call the programs sequentially. The first program was to construct the E-VAN parameters for simulation (E_VAN_Para.m). Parameters for the vehicle information, transmission, battery module, traction motor and the control unit were input in this file. After loading the parameters, the script call the main program, E_VAN_Sim.mdl, coded in the Simulink platform. The graphical program was demonstrated in Figure 9. The left-side block is the control strategies which governs the E-VAN dynamics at the middle and the right-hand side blocks. The vehicle information will then be sent back to the control block for commands at the next time step.

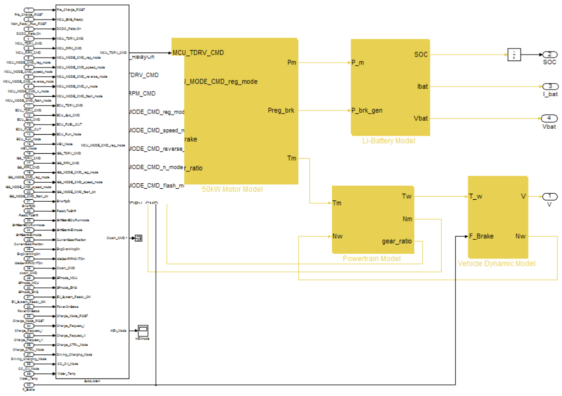

Figure 9: E-VAN-Sim Vehicle Dynamics

From above programs and Simulink model, performance evaluation and control strategy designs can be efficiently evaluated.

4. E-Van-Sim Simulation

In this Section, the simulation results of E-Van-Sim are demonstrated. Figure 10 illustrates testing driving cycle: ECE40. By properly tuning the PID values, the speed error can be limited within 3 kph. Hence, the whole simulation results are trustworthy.

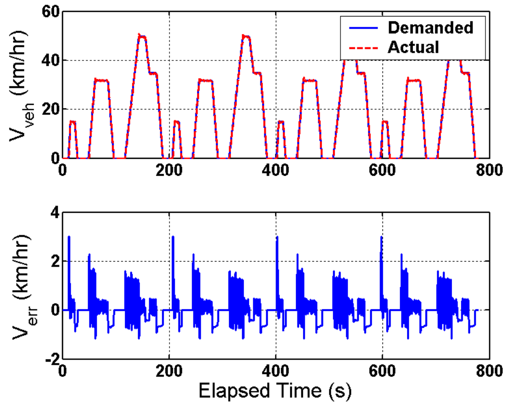

Figure 10: ECE40 Driving Cycle and Speed Error

The top plot in Figure 11 illustrates the motor torque. It shows that the torque sharply rises at the acceleration period. The maximum torque exceeds 80 N-m. As the period of constant speed, the motor torque will decrease to a constant value (15 N-m). Note that the chattering speed is due to the pedal/brake control from the driver. The second and third plots show that motor speed and the wheel speed. It is obvious that the variation of speed is proportional to the speed of ECE40. That is because of the fixed gear ratio.

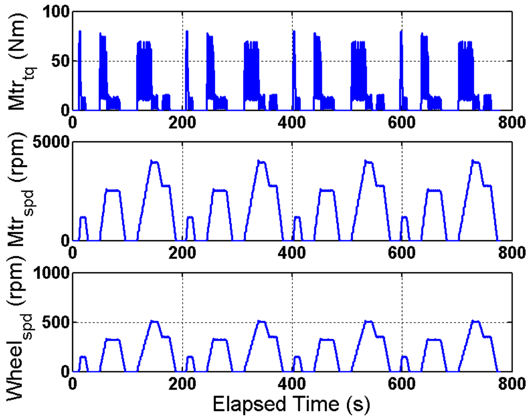

Figure 11: Motor torque, Motor Speed and the Wheel Speed

Figure 12 depicts the motor traction power and the regenerative power. The variation trend of the power is similar to the motor torque that the power raises at the acceleration portion. The maximum output power is 25 kW. Contrarily, the regenerative power occurs at the deceleration period, and the maximum value is 6 kW.

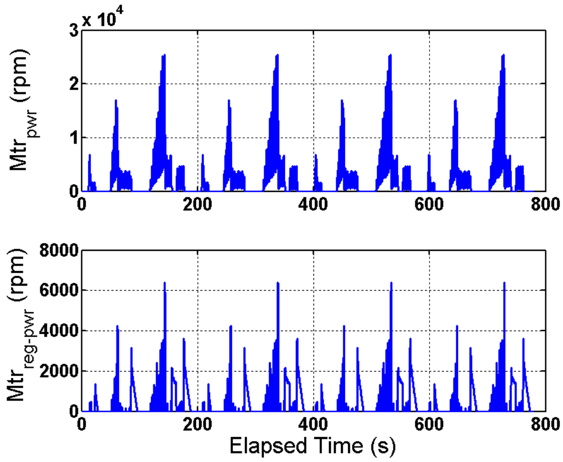

Figure 12: Motor Traction and Regenerative Power

For the high-power battery module, as shown in Figure 13, it shows that the battery SOC drops 2.03% after four ECE40 cycles. The SOC decreases as the motor drives the vehicle, while increases while the regenerative power recharges the battery. The second plot shows that the battery voltage drops because of the battery current (as shown in the third plot) rises. The voltage recovers as the current decreases. Similarly, the chattering phenomenon is due to the fast switch of the pedal and brake. The stable battery voltage slightly descends after four ECE40 cycles.

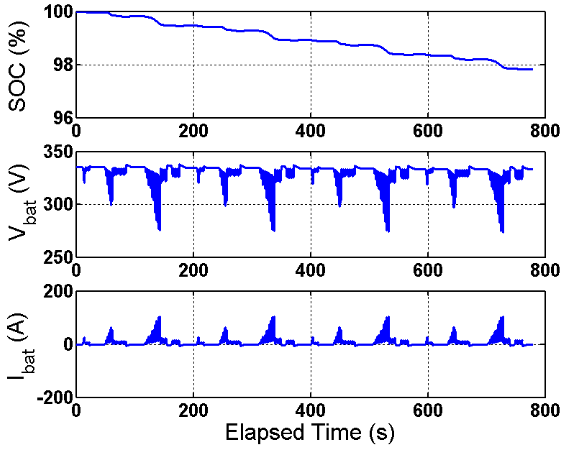

Figure 13: Battery SOC, Battery Voltage and Battery Current

Figure 14 demonstrates the quick response of the pedal and brake signals by a PID controller. The maximum throttle reaches 100% which indicates the maximum torque of the designed motor should be enhanced. The brake signal also reaches 100% at some points. Since the tractive motor torque can be enlarged in the near future, the regenerative torque can be improved simultaneously.

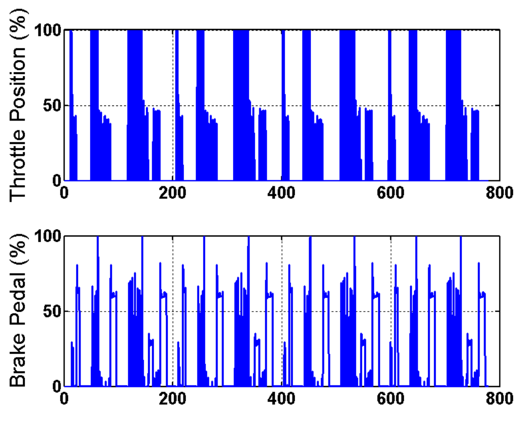

Figure14: Throttle Position and the Brake Signal

Figure 15 demonstrates the variation of the motor driving efficiency and the generation efficiency. The traction efficiency keeps above 85% and the maximum value is 92%. It means the motor can drive the vehicle efficiently. For the generation efficiency, it varies from 78% to 92%. The chattering is because of the brake signal. Figure 16 further demonstrates the operation points of the motor. To shift the operation points to the most efficient area (middle speed and middle torque), the gear ratio can be modified.

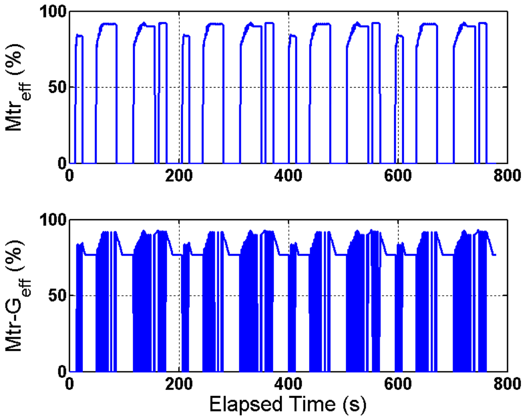

Figure 15: Motor Driving Efficiency and the Generation Efficiency

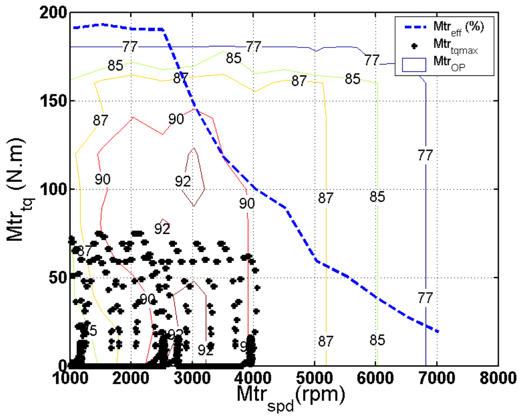

Figure16: Operation Points on the Motor Performance T-N Contour

5 Conclusion

ITRI, as an outstanding automotive research institute in Taiwan, has a great achievement in developing various types of simulators for performance analysis and control strategies. In this study, E-Van-Sim, a self-produced software for ITRI electric vans is successfully developed. By parameter input, system/subsystem dynamics construction, control strategy integration, and the simulation plots, the R&D efficiency of the ITRI E-Van can be obviously raised.

In the near future, due to the low-order vehicle/subsystem dynamics but with high model accuracy, the on-line (real-time) simulation and the HIL development can be developed as shown in Figure 17.

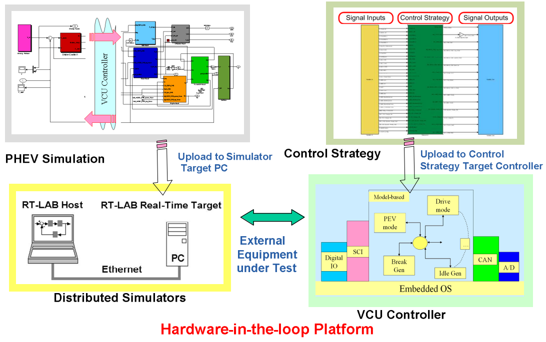

Figure17: Structure of the E-VAN HIL platform

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