Load Power Estimation Using the Extended Kalman Filter of Dynamic Wireless Charging System for Electric Vehicles

Nguyen Tuan Vuong[1], Ngo Quy Thien[1] , Nguyen Xuan Khai[1], Nguyen Thi Diep[2], Nguyen Kien Trung[1*]

[1]Advanced Power Electronics Systems laboratory (APES lab), School of Electrical Engineering, Hanoi University of Science and Technology , Hanoi, Vietnam.

[2]Faculty of Automation and Control, Electric Power University, Hanoi, Vietnam.

vuong.nt174379@sis.hust.edu.vn, thien.nq174233@sis.hust.edu.vn, khai.nx173970@sis.hust.edu.vn, trung.nk1@hust.edu.vn, diepnt@epu.edu.vn

***Abstract*— This paper presents a method to estimate the output power more accurately. Because the car is moving continuously then the parameters in the system will change. So a kalman filter is proposed to calculate the output power. It has considered noise and has an error compensation step then the estimated parameters will be more accurate. Finally, the simulation and experimental results have stabilized with the static deviation reduced from 2.72% to 0.69%, the overtime reduced from 4.42ms to 3.0ms, the efficiency up to more 90% with bilateral LCC structure compensator.**

Keywords—Dynamic charging system, Extended Kalman Filter, double-sided LCC, state-space model, soft switching ZVS, load estimation.

I. INTRODUCTION

To overcome the environmental problem and deplete fossil fuels, the solution is to use electrical vehicles. The dynamic charging system in [1] is the advanced system where the chargers are arranged on the road. Cars can be charged when running on this road, so electric cars can travel longer distances.

The previous studies of the topic have proposed to use the two-sided LCC compensation circuit structure [3]. It gived the power estimation formula using only the measurement information on the transmitting to stable control of charging capacity [2]. However, a real system under the influence of the environment, the parameters will change from the design values. At the same time the measured data are also affected by noise and equipment error. So, the old control method will become less accurate and unstable.

Thus, this report presents a proposed using the Kalman filter to estimate the state. It has considered noise and has an error compensation step, the estimated parameters will be more accurate. From the estimated parameters we calculate the power on the load and control this value stably.

II. THEORY

A new method with the circuit model in [3] is researched. The exact determination of load-side power for EV is based on two main steps. Firstly, we determine the input power. And then, we measure the RMS current flowing through the transmission coil [4]. After that, it is caculated the state variables with the Extended Kalman Filter (EKF).

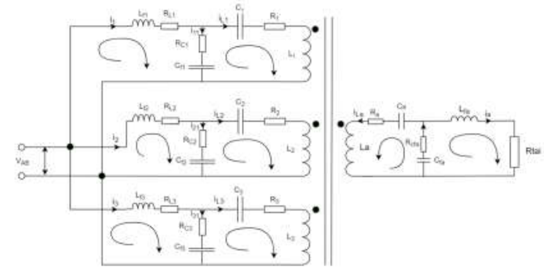


Fig.2.1. The LCC circuit model of Dynamic Charging system

To apply the EKF method, this paper provided a new continous state model (1), when the input signal u is output voltage (v_{AB}) and the output signal y is I_{L1}^2 .

$$\begin{cases} \dot{x} = \overline{A}x + \overline{B}u \\ y = h(x) \end{cases} \quad (1)$$

Then, the Kalman Filter is designed by converting the above model to a discrete domain with considering the effect of noise in (2)

$$\begin{cases} x_{k+1} = Ax_k + Bu_k + Gw_k \\ y_k = h(x_k, v_k) \end{cases} \quad (2)$$

where process noise w_k and measurement noise v_k have corresponding variances Q and R, respectively. After that, we establish the calculaton process of EKF which includes three steps: initializaion, predication and correction.

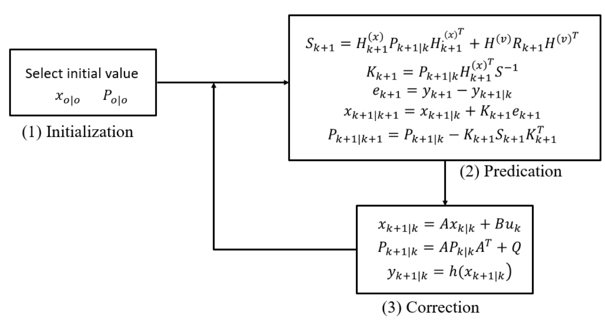


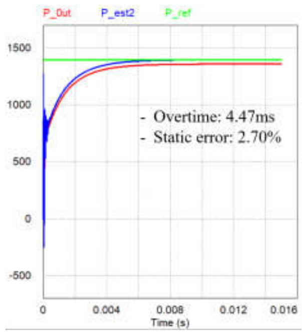
Fig.2.2. The calculation process of EKF

III. SIMULATION RESULT

To verify the analys and the proposed technique, a simulation model on PSIM software is designed with 85kHz frequency and an output power of about 1.5kW.

Firstly, this method performs closed-loop control with the designed PI controller without noise and obtain power value.

Wireless Power Tranfer Group, APES lab, Department of Industrial Automation – Estimating Load Capacity by Using the Extended Kalman Filter of Wirelessly Dynamic Charging EV System.
The 1st International Symposium on Power, Energy and Cybernetics (ISPEC) 2020.



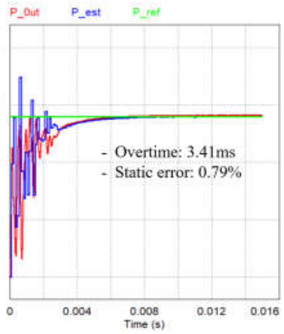
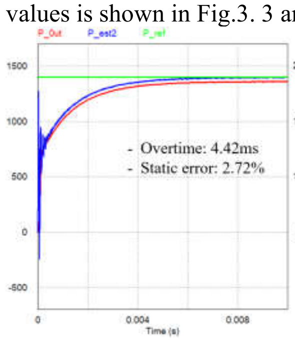


Fig.3.1. Use estimated formula Fig.3.2. Use EKF

Then, the simulation changes the parameters of some elements in the system that differs from 5% designed values and add measurement noise in about 10%, so the power values is shown in Fig.3. 3 and Fig.3. 4.



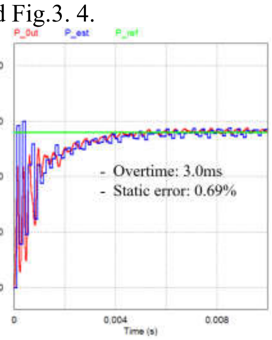


Fig. 3.3. Use estimated formula Fig. 3.4. Use EKF

So as you can see, the application of the EKF has resolved better than previous studies in estimating the power on load impedance.

IV. EXPERIMENT RESULT

This prototype is built to simulate the dynamic charging procession in order to test the theory in Section II and the simulation in Section III. The photo of experimantal device is shown in Fig. 4.1. Set the system operating frequency 85 kHz, the load is 53.3 Ohm.

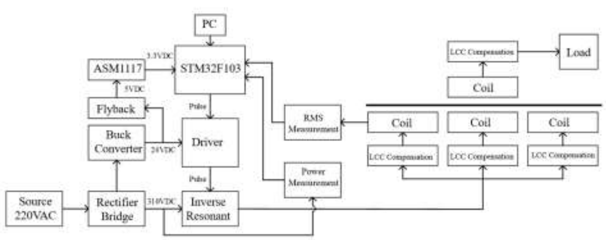


Fig. 4.1. Experimental block diagram of Dynamic Charging System

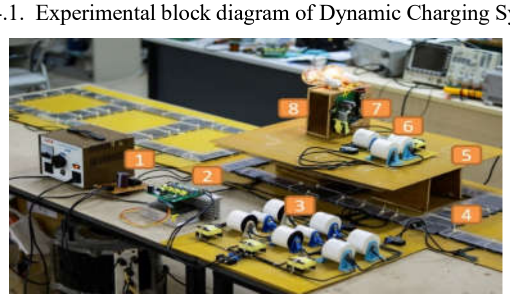
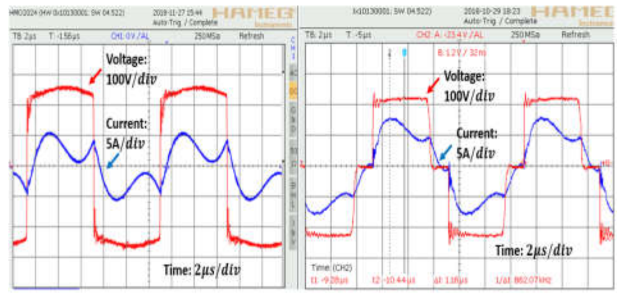


Fig. 4.2. Experimental model of Dynamic Charging system



(a) (b)

Fig.4. 3. Voltages and currents after inverter.
(a) U_{DC}*=280V,* θ*=180°* *(b)* U_{DC}*=220V,* θ*=150°.*

V. CONCLUSION

In this paper, Extended Kalman Filter has been presented and discussed. The proposed method is able to improve efficiency up to more than 90%. Moreover, the static deviation and overtime are significantly reduced. Which showed that the technique is more accurate than previous results. However, as the process noise and the measurement noise change complicatedly, the estimation is not guaranteed.

VI. ACKNOWLEDGEMENT

This reseach was supported by Dr. N. K. Trung and Advanced Power Electronics Systems laboratory (APES lab), Department of Industrial Automation, School of Electrical Engineering.

REFERENCES

[1] Fei Lu, Hua Zhang, Heath Hofmann, and Chunting Chris Mi "A Dynamic Charging System With Reduced Output Power Pulsation for Electric Vehicles" IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 63, NO. 10, OCTOBER 2016.

[2] Kim, Min-Kook, Joo, Dong-Myoung and Lee, Byoung Kuk, "Design and Control of Inductive Power Transfer System for Electric Vehicles Considering Wide Variation of Output Voltage and Coupling Coefficient ," IEEE Transactions on Power Electronics,TPEL-Reg-2017-11-2091,02-Nov-2017.

[3] S.Li, W.Li, J.Deng, T.D. Nguyen, and C.C.Mi, "A double-sided LCC compensation network and its tuning method for wireless power transfer," IEEE Trans. Veh. Technol., vol. 64, no. 6, pp. 2261–2273, Jun. 2015.

[4] Minkook Kim, Dong-Myoung Joo, Byoung Kuk Lee and Dong-Gyun Woo , "Design and Control of Inductive Power Transfer System for Electric Vehicles Considering Wide Variation of Output Voltage and Coupling Coefficient ,"