# MULTI-RATE OPTIMAL CONTROL FOR BIDIRECTIONAL DC-DC CONVERTER OF EV CHARGER

**CHANG-HYUN KIM**

Dept. of Electricity, Vision College of Jeonju, South Korea
E-mail: chkim@jvision.ac.kr

**Abstract -** In this paper, we propose the optimal control method for bidirectional DC-DC power converter for electric vehicles based on a multi-rate state estimation. The proposed multi-rate optimal controller has two parts, the fast-rate discrete Kalman filter and the optimal controller. The Kalman filter observes all states with respect to the fast sampling time based on the discrete model from a slowly measured output from current sensor. The optimal control law is determined by linear quadratic optimization for the discrete time system, using lifting operator. The proposed control method shows the improved performance by the fast-rate actuation despite of the slow-rate sensing. The numerical simulation shows the effectiveness of the proposed control method.

**Index Terms -** Multi-rate Control, DC-DC Converter, EV Charger, Kalman Filter

## I. INTRODUCTION

In the development of electric vehicles (EVs), the electric power charger plays a key role. For the EV batteries, the common charging profiles are practically constant current (CC) and constant voltage (CV) charging [1]. In this paper, we focus on CC charging control limited in a constant voltage level. The control efficiency of the battery charging has a strong dependency on the performance of a current sensor. The sensing rate and sensing accuracy have the water bad effect such that the fast-rate measurement causes the deterioration of sensing quality [1]. The proposed control method is determined for the multi-rate systems by lifting operation, based on Kalman filter and linear quadratic (LQ) optimal control. The Kalman filter estimates all states at the fast time step from the mathematical model of the DC-DC converter with respect to the slowly measured output from current sensors. The control consists of two parts, the fast actuator designed by LQ optimization and the multi-rate estimation [2]. The effectiveness of the proposed control method is verified by the numerical simulation and experiment.

## II. DC-DC CONVERTER OF EV CHARGER

Figure 1 depicts the structure of DC-DC converter of EV charger. The controller is determined by CC and CV charging. The continuous and discrete mathematical models of DC-DC converter are represented as Eq. (1) and (2), respectively [3].

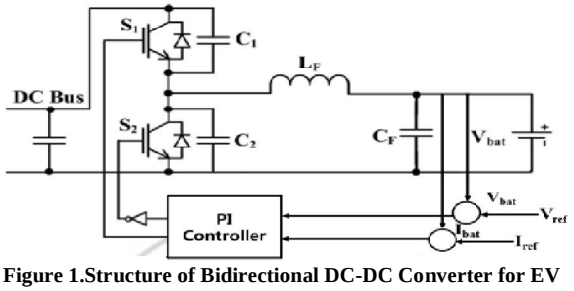


**Figure 1.Structure of Bidirectional DC-DC Converter for EV**

$$\begin{bmatrix} \frac{di(t)}{dt} \\ \frac{du_o(t)}{dt} \end{bmatrix} = \begin{bmatrix} 1 & -\frac{1}{L}(1-S) \\ \frac{1}{C}(1-S) & -\frac{1}{RC} \end{bmatrix} \begin{bmatrix} i(t) \\ u_o(t) \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} u_i(k) \quad (1)$$

$$\begin{bmatrix} i(k+1) \\ u_o(k+1) \end{bmatrix} = \begin{bmatrix} 1 & -\frac{T_s}{L}(1-S) \\ \frac{T_s}{C}(1-S) & 1-\frac{T_s}{RC} \end{bmatrix} \begin{bmatrix} i(k) \\ u_o(k) \end{bmatrix} + \begin{bmatrix} \frac{T_s}{L} \\ 0 \end{bmatrix} u_i(k) \quad (2)$$

Where $S$ is a switching factor for buck and boost modes.

## III. PROPOSED CONTROL METHOD

Let $F_T$ and $S_T$ be the fast and slow sampling time for the controller and current sensors. The sampling time is represented as $t = S_T k + F_T i$ with $k = 0, 1, \ldots$ and $i = 0, 1, \ldots, R_m - 1$.
By the lifting operator, the discrete time multi-rate systems are remodeled as following [2]:

$$\begin{aligned} x(k+1,0) &= \tilde{\Phi} x(k,0) + \tilde{\Gamma}_w \tilde{w}(k) + \tilde{\Gamma}_u \tilde{u}(k) \\ \tilde{z}(k,0) &= \tilde{C}_z x(k,0) + \tilde{D}_{zw} \tilde{w}(k) + \tilde{D}_{zu} \tilde{u}(k) \\ y(k,0) &= C_y x(k,0) + \tilde{D}_{yw} \tilde{w}(k) + \tilde{D}_{yu} \tilde{u}(k) \end{aligned} \quad (3)$$

$$\tilde{\Phi} = \Phi^{R_m}, \; R_m = S_T / F_T,$$

$$\tilde{\Gamma}_w = [\Phi^{R_m-1}\Gamma_w \quad \Phi^{R_m-2}\Gamma_w \quad \cdots \quad \Gamma_w],$$

$$\tilde{\Gamma}_u = [\Phi^{R_m-1}\Gamma_u \quad \Phi^{R_m-2}\Gamma_u \quad \cdots \quad \Gamma_u],$$

$$\tilde{C}_z = \begin{bmatrix} C_z \\ C_z\Phi \\ \vdots \\ C_z\Phi^{R_m-1} \end{bmatrix},$$

$$\tilde{D}_{zw} = \begin{bmatrix} D_{zw} & 0 & \cdots & 0 \\ C_z & D_{zw} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ C_z\Phi^{R_m-2}\Gamma_w & C_z\Phi^{R_m-1}\Gamma_w & \cdots & D_{zw} \end{bmatrix},$$

$$\tilde{D}_{zu} = \begin{bmatrix} D_{zu} & 0 & \cdots & 0 \\ C_z & D_{zu} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ C_z\Phi^{R_m-2}\Gamma_u & C_z\Phi^{R_m-1}\Gamma_u & \cdots & D_{zu} \end{bmatrix},$$

$$\tilde{D}_{yw} = [D_{yw} \quad 0 \quad \cdots \quad 0],$$

$$\tilde{D}_{yu} = [D_{yu} \quad 0 \quad \cdots \quad 0],$$

$$\tilde{z}(k) = \begin{bmatrix} z(k,0) \\ z(k,1) \\ \vdots \\ z(k,R_m-1) \end{bmatrix}, \quad \tilde{w}(k) = \begin{bmatrix} w(k,0) \\ w(k,1) \\ \vdots \\ w(k,R_m-1) \end{bmatrix}, \quad \text{and}$$

$$\tilde{u}(k) = \begin{bmatrix} u(k,0) \\ u(k,1) \\ \vdots \\ u(k,R_m-1) \end{bmatrix}.$$

The state feedback control input $\tilde{u}(k)$ is determined to minimize the $l_2$-norm between the exogenous input $\tilde{w}(k)$ and the exogenous output $\tilde{z}(k)$. The fast estimated state $\hat{x}(k,i)$ is obtained by the Kalman filter from the slowly measured output, $y(k,0)$ such that the estimation has the following two processes [2].

Normal correction update

$$: \hat{x}(k,i+1) = \hat{x}(k,i) + L(y(k,0) - C_y\bar{x}(k,0))$$

Fast prediction update

$$: \bar{x}(k,i+1) = \Phi\hat{x}(k,i) + \Gamma_w w(k,i) + \Gamma_u u(k,i)$$

## CONCLUSIONS

This paper proposes the multi-rate optimal control method in order to obtain the high efficiency of the DC-DC power converter for EV charger in spite of the slowly measured sensor with high accuracy. The multi-rate Kalman filter estimates the states with fast –rate sampling time such that the LQ optimal controller is actuated with respect to the estimated states based on the system model. The proposed compensator shows not only the improved performance, but also guarantees the stability, simultaneously.

## ACKNOWLEDGMENT

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