반도체 변압기의 데이터 기반 제어

바바요미 올루레케, 박기범
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Data-Driven Control of Solid-State Transformers

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ABSTRACT

This study investigates the data-driven control of a solid-state transformer (SST) for application in MVDC grids. The proposed method reduces model-dependence by an ultra-local model of the system, which does not require information about the system's dynamic model. Furthermore, a novel parallel extended state observer (PESO) enables the online estimation of the lumped disturbance and states from measured input and output data. PESO provides more accurate estimation of the lumped internal and external disturbances of the system, especially at low bandwidths. The frequency-domain analysis and time-domain simulation results show that the proposed method has faster dynamic response, and better robustness to parameter uncertainties than conventional model-based control.

1. Introduction

The solid-state transformer (SST) is an emerging technology with several advantages for distribution grids. First, it provides identical functions of voltage transformation. Second, SST has extra benefits of flexible bidirectional power flow control, harmonic compensation, integration of energy storage for grid support, and active voltage and frequency control [1].

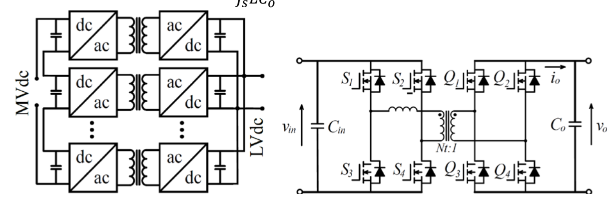
SSTs in medium voltage DC (MVDC) networks facilitate the integration of distributed renewable energy sources to low voltage DC (LVDC) networks, and also the main grid. The dual-active bridge (DAB) converter is an essential component of the SST. Conventional linear control methods, like the proportional-integral (PI) control are popular for their simplicity; but they are limited in disturbance rejection and fast dynamic response [2]. Therefore, this work proposes a new parallel ESO (PESO) to facilitate fast-dynamic, high-disturbance-rejection data-driven control, without an explicit model of the system.

2. Proposed Methodology

The aim is to improve robust control by decreasing the dependence of the controller on the parameters of passive elements by the ultra-local model:

$$\frac{dv_o}{dt} = \psi + \alpha\phi \quad (1)$$

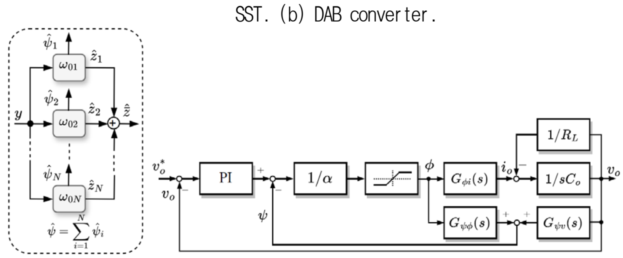
where α is the control input gain, and ψ is the lumped disturbance. $\psi = -\frac{v_o}{R_L C_o}$, and α is a unitless scalar with an initial value of $\alpha_o = \frac{N_t V_{in}(1-4\bar{\phi})}{f_s L C_o}$. ψ is used to account for all



(a) (b)

그림 1 MVDC 그리드용 반도체 변압기. (a) SST의 구조. (b) DAB 변환기.

Fig.1 Solid-State Transformer for MVDC grids. (a) Structure of SST. (b) DAB converter.



(a) (b)

그림 2 제안된 DAB 변환기용 컨트롤러 (a)제안된 PESO(b) 전체 제어 방식.

Fig.2 Proposed controller for DAB converter. (a) Proposed PESO. (b) Overall control scheme.

system disturbances and unmodeled dynamics. The feedback controller requires estimates of v_o and ϕ, which are represented as $\hat{v_o}$ and $\hat{\phi}$, respectively. These estimates are derived from by the conventional extended state observer (ESO), with overall controller scheme in Fig. 2.

where ω_o is the ESO bandwidth.

ESO can only estimate the fundamental component of ψ; but estimating the harmonics of ψ can improve estimation accuracy and the disturbance rejection control performance. Therefore, the new parallel ESO (PESO) in Fig. 2 is proposed. This results in a new transfer function from ϕ to ψ as

$$G_{\psi\phi}(s) = \frac{\hat{\psi}(s)}{\hat{\phi}(s)} = -\frac{-\omega_{01}^2\alpha}{s^2+2\zeta\omega_{01}s+\omega_{01}^2} - \frac{-\omega_{02}^2\alpha}{s^2+2\zeta\omega_{02}s+\omega_{02}^2} - \cdots - \frac{-\omega_{0N}^2\alpha}{s^2+2\zeta\omega_{0N}s+\omega_{0N}^2}. \quad (2)$$

Similarly, by the superposition principle, the new transfer function from v_o to ψ is:

$$G_{\psi v}(s) = \frac{\hat{\psi}(s)}{\hat{v}_o(s)} = \frac{-\omega_{01}^2 s}{s^2+2\zeta\omega_{01}s+\omega_{01}^2} + \frac{-\omega_{02}^2 s}{s^2+2\zeta\omega_{02}s+\omega_{02}^2} + \cdots + \frac{-\omega_{0N}^2 s}{s^2+2\zeta\omega_{0N}s+\omega_{0N}^2} \quad (3)$$

where $\omega_{o1} = \frac{\omega_o}{N^{(N-1)}}$, $\omega_{o2} = \frac{\omega_o}{N^{(N-2)}}$, …, and $\omega_{oN} = \omega_o$.

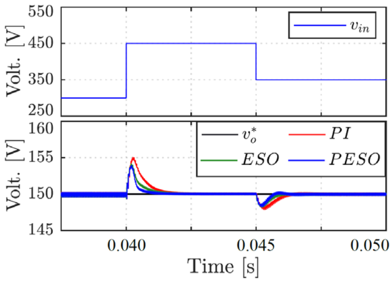


그림 3 입력 전압 변화에 대한 시뮬레이션 결과.

Fig. 3 Simulation results for dynamic changes in input voltage.

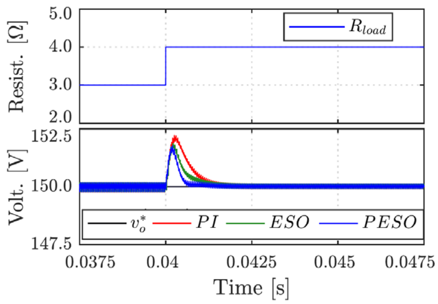


그림 4 하중의 단계적 변화에 대한 시뮬레이션 결과.

Fig. 4 Simulation results for step change in load.

3. Simulation Verification

The proposed control method was implemented with the PLECS software for system parameters in Table 1, with results in Figs. 3 to 6. Variations in the input voltage according to the profile at the top of Fig. 3 create output voltage perturbations as shown. The proposed method has the lowest voltage overshoot, while settling 55% faster than the conventional PI controller, and 25% faster than the conventional ESO-based controller. Also, when the load is changed from 3 to 4Ω (Fig. 4), the proposed method produces the lowest voltage overshoot, with settling time that is more than 50% smaller than both the PI and conventional ESO-based controllers.

Finally, a reference change in the output voltage shows further insights on the performance of the proposed method. While the voltage overshoot is identical with PI controller's, steady state is reached in less than half the time of PI controller. The inductor current plot also shows smaller area of current overshoot; the proposed method's short settling time reduces the thermal power losses in the inductor during the transients.

표 1 시스템 매개변수의 값.

Table 1 Values of the system parameters

Parameter	Value	Parameter	Value
DAB V_{in}	300 V	Sampling T_s	20 us
V_o	150 V	R; L; C	0.25Ω;70uH;1mF
N_t	2	PI (k_p; k_i)	7.53x10^3; 1.37x10^7;

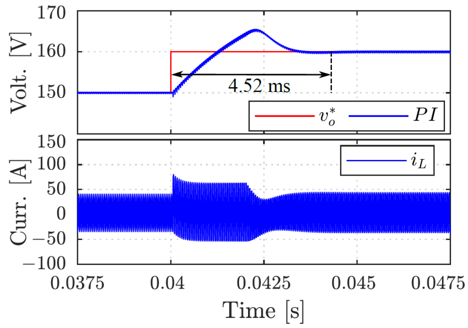


그림 5 기존 PI 제어에 대한 시뮬레이션 결과.

Fig. 5 Simulation results for conventional PI control.

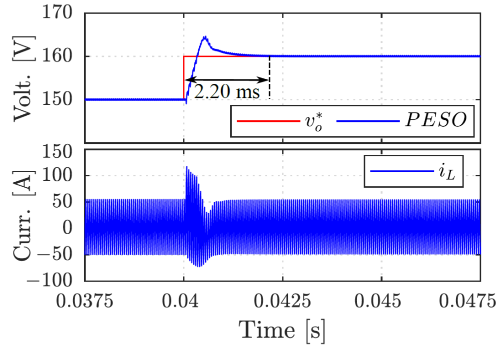


그림 6 제안된 PESO 제어에 대한 시뮬레이션 결과.

Fig. 6 Simulation results for proposed PESO-based control.

3. Conclusion

This paper introduced a new data-driven control method for the DAB converter. It involves less dependence on the system model, and more on measurements of the output. The proposed parallel extended state observer gives fast dynamic response with superior disturbance rejection.

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참 고 문 헌

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