다중레벨 컨버터의 무모델 예측제어

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Model-Free Predictive Control of Multilevel Converters for MVDC Grids

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ABSTRACT

This study proposes a novel model-free predictive control (MFPC) scheme for three-level neutral-point-clamped converters for application in MVDC grids. Conventional model predictive control (MPC) is limited by its sensitivity to parameter mismatch, unmodeled dynamics and measurement noise. To overcome these challenges, in this paper, the prediction models for MFPC are derived solely from a new parallel-cascade extended state observer (PC-ESO). The unique structure of the PC-ESO sustains good disturbance rejection and robustness to parameter uncertainties, while suppressing measurement noises. The results are validated by frequency-domain analysis with MATLAB/SIMULINK and time-domain simulations in PLECS, and show that the proposed MFPC has better overall performance than the model-based predictive control, and also outperforms the results from MPC implemented with conventional extended state observer.

1. Introduction

Medium voltage dc (MVdc) grids support the efficient operation of distribution grids and improve power transfer capacity. Multilevel power converters facilitate the high-power conversion of MVdc grids by their ability to provide high-quality power at low switching frequencies, thus, reducing switching losses [1]. Fig. 1 shows an MVdc grid with three-level neutral-point-clamped (NPC) power converter which is connected to the MVac supply. Conventional high-performance model predictive control (MPC) of NPC converters has high sensitivity to model uncertainties, resulting in non-robust performance. Therefore, this paper proposes an improvement to robustness through model-free predictive control.

2. Proposed Methodology

The state predictions in conventional MPC are sensitive to parameter mismatch, unmodeled dynamics and measurement noise. The full system model can be replaced with an ultra-local model which has less plant parameters. An extended state observer (ESO) is then utilized to predict the grid current, as well as lumped disturbances in the plant, leading to the conventional MPC-ESO method. Nonetheless, MPC-ESO has limited capability for measurement noise suppression.

Therefore, in this study, the hybrid parallel-cascade extended state observer (PC-ESO), which has superior measurement noise suppression, while sustaining parameter robustness [2] is utilized. PC-ESO (Fig. 2) has combined features of parallel ESO and cascade ESO, resulting in hybrid superior disturbance rejection and measurement noise suppression simultaneously. PC-ESO is discretized, and used for grid current predictions with improved robustness as:

$$\begin{cases} \hat{i}_g^{dq}[k+1] = \hat{i}_g^{dq}[k] + T_s\big(\hat{F}_g^{dq}[k] + \alpha v_g^{dq}[k+1]\big) \\ \qquad\qquad -(\gamma_{12}+\gamma_{13})\big(\hat{i}_g^{dq,3}[k+1] - \hat{i}_g^{dq,2}[k+1]\big) \\ \hat{i}_g^{dq}[k+2] = \hat{i}_g^{dq}[k+1] + T_s\big(\hat{F}_g^{dq}[k] + \alpha v_g^{dq}[k+1]\big) \end{cases} \tag{1}$$

where the two-step prediction is applied for computational delay compensation, T_s is the sampling period, $\hat{F}_g^{dq}$ is the estimated lumped disturbance in the *dq* reference plane, $\hat{i}_g^{dq}$ is the estimated grid current, v_g^{dq} is the converter voltage, α is the control input gain, and $\{\gamma_{12}, \gamma_{13}\} = \{2\omega_{02}, 2\omega_{03}\}$ are the ESO estimation error gains. The values of parameters are in Table 1.

The current references $\hat{i}_g^{dq*}$ for cost function J_g are computed by the outer loop PI controller that regulates the MVdc voltage of the dc-link capacitor (V_{dc}).

$$J_g = \big(\hat{i}_g^d[k+2] - \hat{i}_g^{d*}\big)^2 + \big(\hat{i}_g^q[k+2] - \hat{i}_g^{q*}\big)^2. \tag{2}$$

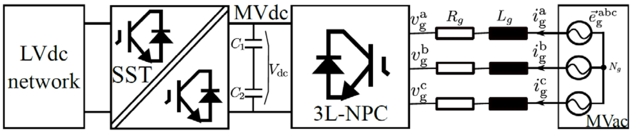

그림 1 멀티레벨 컨버터가 장착된 MVDC 시스템.

Fig.1 MVDC System with multilevel converter.

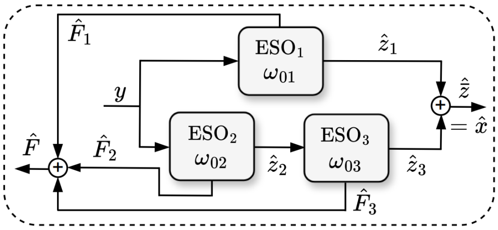

그림 2 강건한 상태 추정을 위한 PC-ESO의 구조.

Fig.2 Structure of PC-ESO for robust state estimations.

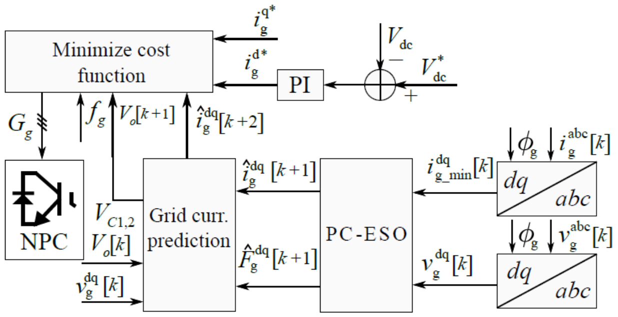

그림 3 멀티레벨 컨버터의 제어 방식.

Fig.3 Control scheme for the multilevel converter.

3. Simulation Verification

For all tests, Gaussian white noise (standard deviation 0.05 p.u.) is added to the measured grid currents (in *dq* domain). Also, the tests are done under parameter mismatch of 2.0L_g.

The steady-state performance (Fig. 4) of the proposed method shows 30% reduction in grid current noise, which is superior to the other conventional methods. Dynamic tests results, where the active power is decreased from 2 to 1 MW at 1.0 s are shown in Figs. 5—6. The simulation results show that the dynamic performance is well-sustained, while the influences of measurement noise and parameter mismatch are significantly suppressed with the proposed method, in contrast to conventional MPC.

표 1 시스템 매개변수의 값.

Table 1 Values of the system parameters

Parameter	Value	Parameter	Value
R_g	1.565 mΩ	Sampling T_s	100 us
L_g	1.55 mH	Bandwidth ω_o	3 krad/s
C_1= C_2	8.4 mF	$\{\omega_{o1},\omega_{o2},\omega_{o3}\}$	$\{\frac{\omega_o^2}{9},\frac{\omega_o}{3},\omega_o\}$
V_{dc}	5 kV	e_g, f_g	3.3 kV, 50 Hz

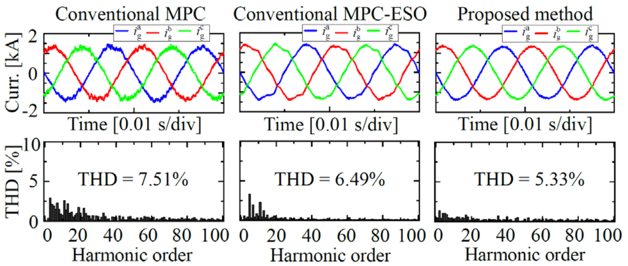

그림 4 측정 소음 조건 동안의 그리드 전류.

Fig.4 Grid current under measurement noise conditions.

3. Conclusion

This paper investigated a new solution to mitigate model uncertainties in model predictive control of multilevel converters. A parallel-cascade extended state observer was applied to model-free predictive control. The simulation results show significant improvements in robustness.

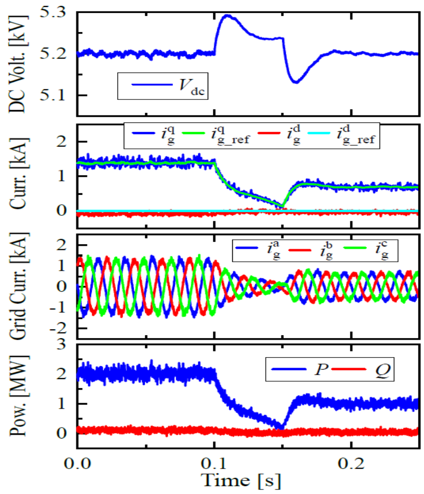

그림 5 파라미터 불일치가 2.0L_g 이고 측정 노이즈가 있는 기존 MPC의 동적 응답.

Fig.5 Dynamic response of conventional MPC under parameter mismatch of 2.0L_g and measurement noise.

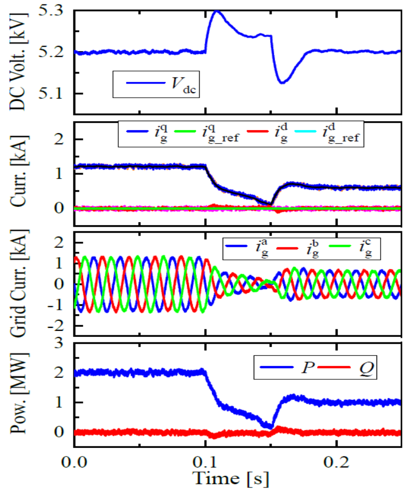

그림 6 파라미터 불일치가 2.0L_g이고 측정 노이즈가 있는 제안 방법의 동적 응답.

Fig.6 Dynamic response of proposed method under parameter mismatch of 2.0L_g and measurement noise.

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참고문헌

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