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Published in:
Proceedings of the 2023 25th European Conference on Power Electronics and Applications (EPE'23 ECCE Europe)

DOI (link to publication from Publisher):
10.23919/EPE23ECCEEurope58414.2023.10264677

Publication date:
2023

Document Version
Accepted author manuscript, peer reviewed version

Citation for published version (APA):
Li, Y., Sahoo, S., Lin, Z., Zhang, Y., Dragicevic, T., & Blaabjerg, F. (2023). An Iterative Learning Based Compensation in Model Predictive Control for DC/DC Boost Converter. In *Proceedings of the 2023 25th European Conference on Power Electronics and Applications (EPE'23 ECCE Europe)* (pp. 1-7). Article 10264677 IEEE. https://doi.org/10.23919/EPE23ECCEEurope58414.2023.10264677

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An Iterative Learning Based Compensation in Model Predictive Control for DC/DC Boost Converter

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***Index Terms*—Non-minimum phase behavior, boost converter, compensation factor, iterative learning.**

***Abstract*—Attributed to the increased processing power of modern microprocessors, model predictive control (MPC) for power converters is gaining more attention. However, the non-minimum phase behavior in DC/DC boost converters complicates the design of model predictive control. When controlling the output voltage directly, it fails to track the reference with short prediction horizons, nevertheless, long prediction horizons cause a heavy computational burden. Although controlling the inductor current is a feasible option with a short prediction horizon, the control accuracy of the output voltage cannot be guaranteed. To address this issue, this work introduces a compensation term into the difference equation of the inductor current. Then the proportion of the compensation term is designed with an iterative learning method to improve the control accuracy. Finally, the results indicate the proposed method can ensure a good control performance with different load occasions.**

I. INTRODUCTION

In recent years, many countries have established new long-term objectives aimed at achieving a cleaner environment. These objectives include reducing energy losses, reducing greenhouse gas emissions, and achieving carbon neutrality. To achieve these targets, there is a growing trend toward promoting the use of renewable energy sources and electric vehicles, as well as increasing the efficiency of buildings and other infrastructure. As a result, DC microgrids gain more attention, which can connect renewable energy systems and EV charging stations, among other applications [1]-[3].

DC microgrids typically consist of small-scale power sources, such as solar panels or wind turbines, as well as energy storage devices and control systems [3]-[4]. Among these components, the boost converter plays a critical role in microgrid systems, as it can help to provide a stable and higher output voltage to the DC bus.

Although boost converters are promising candidates in microgrid systems, they can present some challenges for their controllers, particularly due to their strong non-minimum phase (NMP) behavior [5]-[7]. Non-minimum phase behavior refers to that the output of the boost converter depends not only on the current input but also on past inputs, making it difficult to predict and control. In order to cope with this problem, previous studies have developed various control techniques, including predictive and adaptive control methods [8]-[12]. These methods use mathematical models of the boost converter and algorithms to predict and control its behavior.

When evaluating various control methods, model predictive control (MPC) has emerged as one of the promising solutions due to its ease of implementation, explicit constraints, fast dynamic response, and other advantages [8]. However, as previously mentioned, the non-minimum phase behavior of boost power converters can pose challenges for their control, necessitating the use of long prediction horizon-based MPC to ensure stable operation. Nevertheless, such long prediction horizon-based MPC can be computationally intensive and may require more processing resources [9]. Consequently, there is a need for an MPC approach that balances computational efficiency and control accuracy.

Accurate models of a power converter's dynamics and the overall system behavior are crucial for MPC. If the model lacks sufficient information or contains uncertainties, it can lead to poor control performance. However, obtaining accurate models of the system can be challenging in practice, as it may be difficult to obtain or subject to uncertainty.

In summary, the above issues can be included as how to ensure accuracy and stable operation during the static & dynamic conditions with less computation burden. To eliminate the influence of the non-minimum phase behavior in DC/DC boost converter with a single prediction horizon based MPC, an input linearization method is utilized [8]. The goal of input linearization is to obtain an output with a relative degree equal to the system order and eliminate any hidden internal dynamics. Based on this, the input non-linearities are effectively eliminated. However, the compensation should be designed to ensure accurate tracking during the dynamic process [9]. In addition, the cost function of MPC is designed only by utilizing the inductor current to weaken the influence of NMP behavior [9]. Nevertheless, the system is sluggish to the variation in the output voltage, which results in degradation of performance. Therefore, it incorporates an observer into the control system to improve accuracy [10]. A modified inductor difference equation is proposed in [11]. It avoids using the relationship between the output voltage and the duty cycle value, where the NMP behavior is eliminated. To further improve the control performance of the MPC, the adaptive MPC is widely developed to significantly dissociate MPC from the system's model. An adaptive model and a disturbance observer are built in [12], compared with the conventional MPC, it offers better dynamic performance and is more robust. A data-driven and iterative learning based predictive control is presented in [13]. The pseudo partial derivative which is a parameter to be designed in the iterative learning is determined by the data model. In this case, the non-linear behavior can be accurately described and the control performance is enhanced.

To address the said challenges with data free and light computation burden, this study proposes an inductor current compensation-based MPC method for the boost converter. An iterative learning method is utilized to design the compensation factor. Next, the effect of the learning gain of the iterative learning is analyzed based on the derived relationship between the compensation factor and the output voltage. A suitable learning gain is then selected to ensure convergence.

The rest of the paper is organized as follows. Section II illustrates the discrete model of the boost converter. Section III presents the proposed MPC algorithm. Section IV provides the iterative learning method and gives the guideline for selecting the factor of the compensation item. Two case studies are presented in Section V. Section VI concludes the paper.

II. MODEL OF DC/DC BOOST CONVERTER

Fig. 1 shows the DC/DC boost converter. The state space average equations can be obtained as:

$$\frac{di_L(t)}{dt} = \frac{V_g(t)}{L} - \frac{1-d}{L} V_o(t) \tag{1}$$

$$\frac{dV_o(t)}{dt} = \frac{1-d}{C} i_L(t) - \frac{V_o(t)}{RC} \tag{2}$$

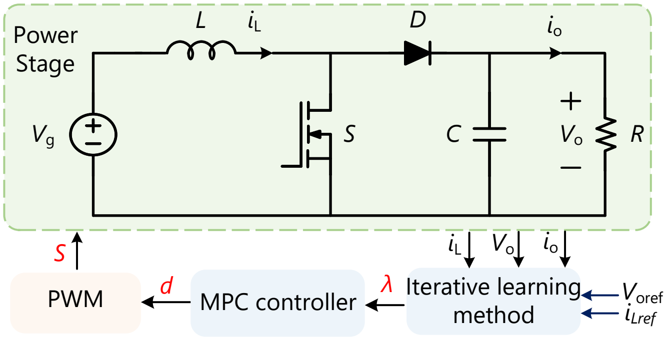

Fig. 1. DC-DC boost converter.

where, i_L is the inductor current, V_g is the input voltage, V_o denotes the output voltage, d represents the duty cycle, and L, C, R are the inductance, output capacitor, and load resistance, respectively.

Assuming that the sampling frequency is relatively high, the equations in (1) and (2) can be transferred into the following discrete forms based on the classical Euler approximation method:

$$i_L(k+1) = i_L(k) - \frac{1-d}{L} V_o(k) T_s + \frac{V_g T_s}{L} \tag{3}$$

$$V_o(k+1) = V_o(k) + \frac{1-d}{C} i_L(k) T_s - \frac{V_o(k) T_s}{RC} \tag{4}$$

where T_s is the switching cycle, and k refers to the k instant. Based on the difference equations (3) and (4), the prediction model for the MPC can be built.

III. PROPOSED COMPENSATION ITEM BASED MPC ALGORITHM

A. The non-minimum behavior analysis

The cost functions can be established based on (3) and (4) respectively which are expressed as:

$$J_L = \sum_{i=1}^{N} (i_L(k+i) - i_{Lref})^2 \tag{5}$$

$$J_V = \sum_{i=1}^{N} (V_o(k+i) - V_{oref})^2 \tag{6}$$

where, N is the prediction horizon, i_{Lref} is the inductor reference and V_{oref} is the output voltage reference. To reduce the computational burden, this paper adopts a prediction horizon of $N = 1$. While the cost function J_V in (6) can be directly used for converters that regulate a stable output voltage, it cannot be applied to the boost converter due to its NMP behavior. Fig. 2 illustrates the tracking failure of the boost converter system when using the cost function in (6). The system's response to changes is delayed and dependent on past values. As a result, if the prediction horizon of the MPC is too short, the controller may not accurately predict the system's response and fail to track its reference 100 V.

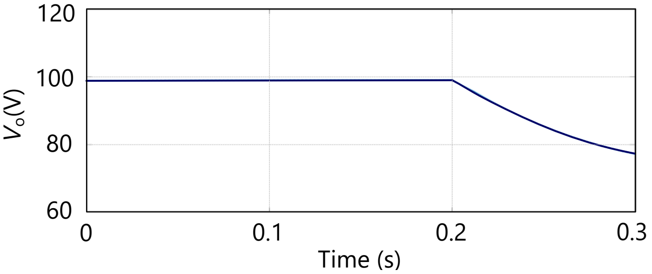

Fig. 2. Output voltage fails to track the reference at 0.2 s in the boost converter with a single prediction horizon.

To address this issue, the cost function (5) is typically used instead of (6) to compensate for the NMP behavior and improve the control performance [10]. However, steady-state error may still exist due to model inaccuracy and load uncertainty. As a result, compensation is necessary to mitigate the system's error.

B. Description of the proposed compensation item based MPC

In a closed-loop control system, the difference between the reference and the actual output is known as the error signal. Based on this, this work also utilizes the error between the output voltage and its reference as the compensation item. Therefore, the difference equation in (3) can be modified as:

$$\begin{aligned} i_L(k+1) =& i_L(k) - \frac{1-d}{L}V_o(k)T_s + \frac{V_gT_s}{L} \\ &- \lambda(V_{oref} - V_o(k)) \end{aligned} \tag{7}$$

The compensation factor λ is a positive value. The compensation item $\lambda(V_{oref} - V_o(k))$ is positive when the output voltage is less than the reference, causing the predicted inductor current value $i_L(k+1)$ to decrease. Since the inductor current reference i_{Lref} is fixed, the optimal duty cycle value from minimizing the cost function in (5) will also decrease. This, in turn, will generate a smaller d and a larger output voltage V_o, which will gradually approach the desired output voltage. The opposite is true when the output voltage is higher than the reference.

Table I: System Parameters.

Parameters	Symbols	Values
Input voltage	V_g	50 V
Output voltage	V_o	100 V
Inductance	L	1 mH
Capacitor	C	2000 μF
Switching cycle	T_s	50 μs
Output power	P	200 W
PI controller parameter	K_p	0.1
PI controller parameter	K_i	10
Reference inductor current	i_{Lref}	$V_{oref}i_o(k)/V_g$
Reference output voltage	V_{oref}	100 V

IV. ITERATIVE LEARNING BASED COMPENSATION FACTOR DESIGN

A. Design of the compensation factor

Although the introduction of the compensation item has significantly improved control accuracy, the selection of the compensation factor is critical to its control performance. A poorly designed compensation factor can prevent the system from reaching the desired control accuracy. Additionally, a fixed compensation factor may not be suitable for handling dynamics.

Iterative learning is a powerful and flexible technique that can be used to improve the accuracy of the model. The main idea behind iterative learning is to use the error from previous iterations to improve the accuracy of the model in subsequent iterations. This is typically done by using some form of gradient descent to adjust the model's parameters in the direction that reduces the error. With each iteration, the model gets closer to the optimal parameters that minimize the error.

In this study, the model parameter to be updated is the compensation factor λ, and the error to be reduced is the output voltage error. Therefore, understanding the relationship between the compensation factor and the output voltage error is fundamental for the iterative learning method.

According to the operating principle of the MPC, the optimal duty cycle can be based on the following equation:

$$\begin{gathered} \frac{\partial J_L}{\partial d} = 0 \\ subject\ to: d \in (0,1) \end{gathered} \tag{8}$$

Then, the optimal duty cycle is derived according to (5), (7), and (8):

$$\begin{aligned} d =& 1 - \frac{Li_L(k)}{V_o(k)T_s} - \frac{V_g}{V_o(k)} + \frac{\lambda E + i_{Lref}}{V_o(k)T_s}L \\ =& G(\lambda) \end{aligned} \tag{9}$$

Where $E = V_{oref} - V_o(k)$. Notice that $G(\lambda)$ is limited within (0,1). Next, the relationship of the duty cycle to the output voltage can be obtained from (4). Substituting (7) into (4), we can obtain:

$$V_o(k+1) = V_o(k) + \frac{1-G(\lambda)}{C} i_L(k)T_s - \frac{V_o(k)T_s}{RC} \tag{10}$$

Therefore, the relationship of the compensation factor λ to the output voltage is obtained:

$$\begin{aligned} V_o(k+1) &= -\frac{Li_L(k)E}{V_o(k)C}\lambda + D(k) \\ &= Q(k)\lambda + D(k) \end{aligned} \tag{11}$$

where, $Q(k)$ represents the compensation factor on the output voltage, $D(k)$ is regarded as the external disturbance.

B. Convergence Analysis

Fig. 3 shows the block diagram of the closed-loop iterative learning control, which is employed in the studied system.

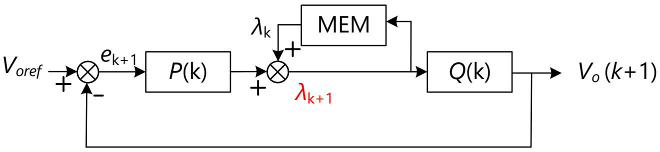

Fig. 3. Diagram of the iterative learning method.

Based on the iterative learning control algorithm, the learning law can be expressed as:

$$\lambda_{k+1}(k+1) = \lambda_k(k) + P(k)e_{k+1}(k) \tag{12}$$

where $P(k)$ is the learning gain based on the learning law. Further, $e(k)$ is the error between the output voltage and the reference, which is described as:

$$e_{k+1}(k) = V_{oref} - V_{o,k+1}(k) \tag{13}$$

According to (12) and (13), the convergence radius can be obtained as:

$$\rho = \left| \frac{e_{k+1}(k)}{e_k(k)} \right| = \frac{1}{|1 + Q(k)P(k)|} \tag{14}$$

It is proved that if the convergence radius ρ in (14) is less than 1, then the error will gradually converge to 0. Therefore, $P(k)$ should satisfy the following equation:

$$|1 + Q(k)P(k)| > 1 \tag{15}$$

The calculation process of the proposed method.

Algorithm: Iterative based Compensation (IC) in MPC algorithm for the boost converter

```
function: IC-MPC
Input: [$i_L(k)$, $V_o(k)$, $i_o(k)$, $V_{oref}$, $i_{Lref}$]
Output: duty cycle $d(k)$
    // Step 1: Compute learning parameter $P(k)$
    $P(k) = -0.01 sign(V_{oref} - V_o(k))$
    // Step 2: Compute compensation factor $\lambda$
    $\lambda = \lambda(k) + P(k)(V_{oref} - V_{o,k+1}(k))$
    // Step 3: Predict $i_L(k+1)$
    $i_L(k+1) = i_L(k) - \frac{1-d}{L}V_o(k)T_s + \frac{V_gT_s}{L}$
                $-\lambda(V_{oref} - V_o(k))$
    // Step 4: Obtain optimal duty cycle $d(k)$
    Compute $d(k)$ with $\partial J/\partial d = 0$
    // Step 5: Apply conditions to determine $d(k)$
    if $0 < d < 1$ then
        $d(k) = d$
    else if $d \leq 0$ then
        $d(k) = 0$
    else
        $d(k) = 1$
    end if
    // Step 6: Update parameter
    $\lambda = \lambda(k)$
    Return $d(k) = d$
end function
```

Combining (11) and (15), the convergence condition can be derived as:

$$\left| 1 - P(k)\frac{Li_L(k)E}{V_o(k)C} \right| > 1 \tag{16}$$

As seen, if $P(k)Q(k)$ is always a positive value, then $1 + P(k)Q(k)$ is larger than 1 and the convergence condition is satisfied. However, because of the uncertainty of $V_{oref} - V_o(k)$, it cannot ensure $P(k)Q(k)$ to be positive or negative if $P(k)$ is a positive or negative value.

To ensure the condition in (16), we select the $P(k)$ as:

$$P(k) = -0.01 sign(E) \tag{17}$$

As seen, when V_{oref} is larger than $V_o(k)$), $Q(k)$ is positive and $P(k)$ is negative. In this case, $1 - P(k)Q(k)$ is larger than 1 which satisfies the convergence condition. When V_{oref} is smaller than $V_o(k)$, $Q(k)$ is negative and $P(k)$ is positive. Therefore, $1 - P(k)Q(k)$ is larger than 1 which means the system can converge. To better illustrate the calculation process of the proposed method, the pseudo-code is presented above. It should be noticed that because the duty cycle in (9) is bounded with (0,1), the λ is also limited with the following equation:

$$\begin{cases} ifE \geq 0, \lambda \in (\frac{-FV_o(k)T_s-Li_{Lref}}{LE}, 1-\frac{FV_o(k)T_s+Li_{Lref}}{LE}) \\ ifE < 0, \lambda \in (1-\frac{FV_o(k)T_s+Li_{Lref}}{LE)}, \frac{-FV_o(k)T_s-Li_{Lref}}{LE}) \end{cases} \tag{18}$$

Where $F = V_g/V_o(k) - Li_L(k)/(V_o(k)T_s)$.

V. SIMULATION RESULTS

In this section, simulation results are presented to demonstrate the effectiveness of the proposed method. The simulations are conducted for two case studies using the parameters given in Table I.

A. *Dynamic performance with load and output voltage reference variations*

Fig. 4 displays the output voltage results of the proposed MPC with the learning gain of $-0.01sign(V_{oref} - V_o(k))$ and the inductor current control-based MPC (ICC-MPC) which utilizes the difference equation in (3) and cost function in (5). The proposed method achieves stable operation at 100 V, accurately tracking the output voltage reference. Furthermore, during the dynamic process when the load changes at 0.1 s, the system can track the reference and stabilize at 100 V with only a 0.1 V undershoot. Conversely, the ICC-MPC fails to accurately track the reference output voltage accurately.

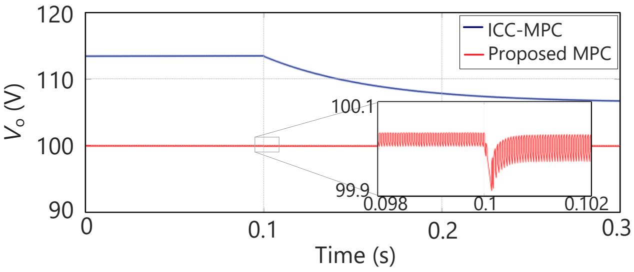

Fig. 4. Output voltage with the ICC-MPC and the proposed method when the load changes from 100 Ω to 50 Ω.

Fig. 5 illustrates the output voltage response of the proposed MPC and the ICC-MPC with the output voltage reference changing from 100 V to 120 V. As shown, the proposed method stabilizes the output voltage at 100 V initially, and after 0.1 s, the output voltage smoothly tracks the reference and stabilizes at 120 V. In contrast, the ICC-MPC controlled the output voltage is 114 V before the output voltage steps and finally stabilizes at 132 V which shows an inaccurate control performance.

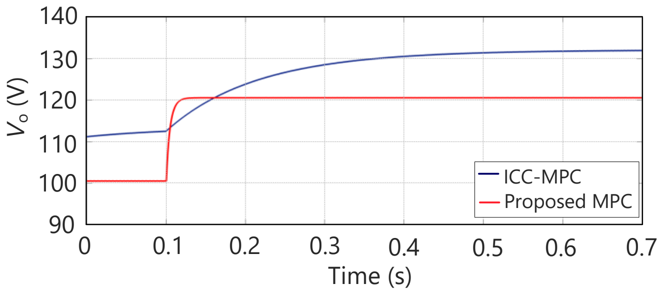

Fig. 5. Output voltage with ICC-MPC and the proposed method when output voltage reference changes from 100 V to 120 V.

B. *Dynamic performance with dc motor load*

This case study aims to evaluate the effectiveness of the proposed method on the boost converter-fed dc motor system, with a rated speed of 1750 RPM, a rated armature voltage of 240 V, and a field voltage of 300 V.

The requirement is to adjust the speed of the motor from 1750 RPM to 1000 RPM. To achieve this using the proposed method, it is necessary to adjust the output voltage of the boost converter from 240 V to 160 V.

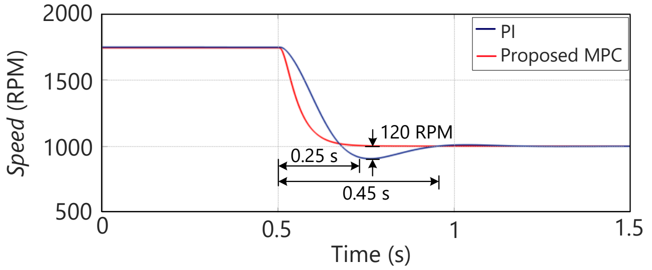

Fig. 6. Speed of the dc motor with the proposed method and the PI controller.

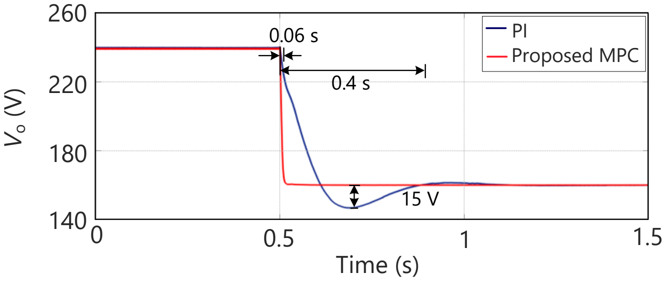

Fig. 7. Output voltage of the boost converter with the proposed method and the PI controller.

In Fig. 6, the speed of the dc motor changes smoothly from 1750 RPM to 1000 RPM using the proposed method. Furthermore, when compared with the PI-controlled boost converter-fed dc motor, the proposed method demonstrates a faster dynamic response, requiring only 0.25 s seconds to stabilize. In contrast, the PI controller needs 0.45 s to decrease the speed to 1000 RPM. Besides, an undershoot which is 120 RPM can be observed during the dynamic process with the PI controller. While it has no obvious undershoot with the proposed MPC. The adjustment of the output voltage from 240 V to 160 V corresponds with the dynamic process of the speed in Fig. 6. As shown in Fig. 7, the proposed method achieves stabilization at 160 V in just 0.06 s, while the PI controller takes 0.4 s to stabilize at the same voltage. Similarly, a 15 V undershoot is observed with the PI controller while it is no obvious voltage undershoot with the proposed method.

C. Robustness verification

In real-world applications, it is challenging to obtain an accurate model of the converter. Consequently, it becomes crucial to maintain control accuracy even when there is a mismatch between the existing system and the model. To evaluate the robustness of the proposed method against parameter mismatch, simulations were performed by varying the inductor from 1.0 mH to 0.8 mH in the model in Fig. 8 and the capacitor from 2000 μF to 1500 μF in the model in Fig. 9.

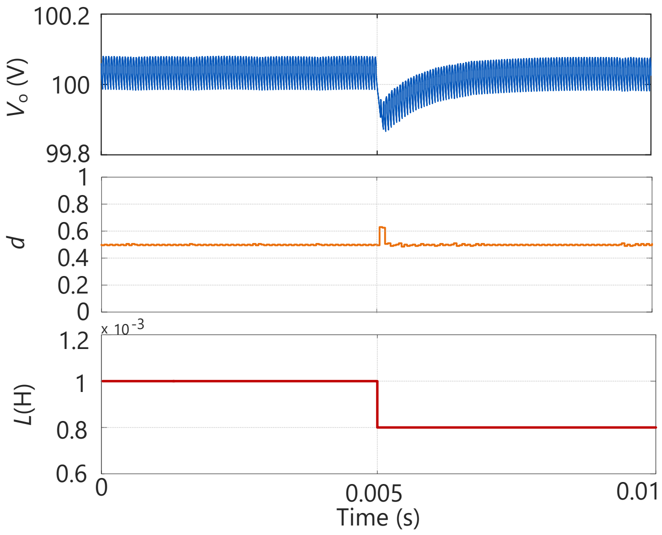

Fig. 8. Output voltage with the proposed method when the inductance value L mismatches.

As seen, when the inductance value L and the capacitor value C used in the model change from 1 mH to 0.8 mH and 2000 μF to 1600 μF respectively at 0.005 s, the output voltage can maintain its reference value with 100 V. When the inductance value changes, the output voltage transits smoothly with a slight undershoot of 0.1 V which shows good robustness. When the capacitor value changes, it also shows a good control ability with a slight overshoot of 0.05 V.

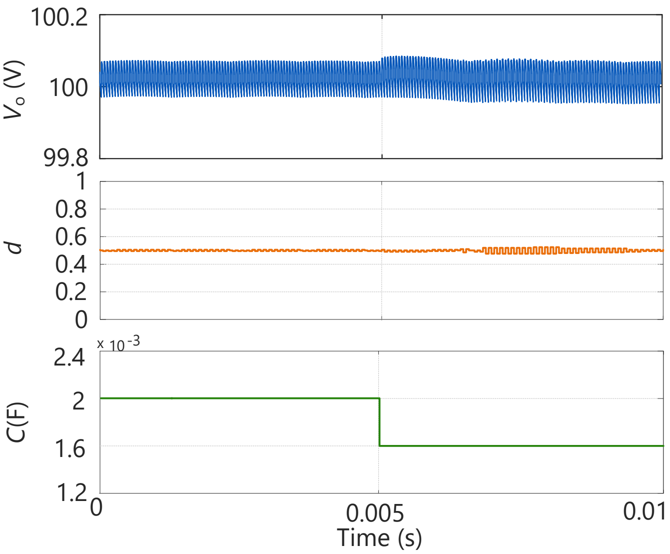

Fig. 9. Output voltage with the proposed method when the capacitor value C mismatches.

As a result, the proposed algorithm can design a compensation factor to enhance control accuracy, effectively addressing the non-minimum phase (NMP) behavior and achieving fast dynamic performance across different load types. Furthermore, the controller exhibits robustness even in the presence of a parameter mismatch between the actual system and the model used.

VI. CONCLUSION

In this investigation, the aim was to examine the design of a compensation item for the model predictive control-based boost converter. Initially, the influence of non-minimum phase behavior was mitigated by introducing the output voltage error into the difference equation of the inductor current. Subsequently, an iterative learning-based compensation factor design method was proposed to further enhance control accuracy.

From the simulation results, they show that the proposed method can provide an accurate control of the output voltage which stabilizes at 100 V with regard to the 100 V reference. Besides, the proposed method can cope well with the load and output voltage reference variations during the dynamic response. Additionally, the robustness is also guaranteed with the proposed controller when parameters mismatch with the real system and the model.

REFERENCES

[1] J. M. Guerrero, J. C. Vasquez, J. Matas, et.al, "Hierarchical control of droop-controlled ac and dc microgrids—a general approach toward standardization," *IEEE Trans Ind. Electron.*, vol. 58, no. 1, pp. 158-172, Jan. 2011.

[2] T. Dragičević, X. Lu, J. C. Vasquez and J. M. Guerrero, "DC Microgrids—Part I: A Review of Control Strategies and Stabilization Techniques," *IEEE Trans Power Electron.*, vol. 31, no. 7, pp. 4876-4891, July 2016.

[3] S. Sahoo, T. Dragičević and F. Blaabjerg, "An event-driven resilient control strategy for DC microgrids," *IEEE Trans Power Electron.*, vol. 35, no. 12, pp. 13714-13724, Dec. 2020.

[4] P. C. Loh, D. Li, Y. K. Chai and F. Blaabjerg, "Autonomous Operation of Hybrid Microgrid With AC and DC Subgrids," *IEEE Trans Power Electron.*, vol. 28, no. 5, pp. 2214-2223, May 2013.

[5] Z. Chen, W. Gao, J. Hu and X. Ye, "Closed-Loop Analysis and Cascade Control of a Non-minimum Phase Boost Converter," *IEEE Trans Power Electron.*, vol. 26, no. 4, pp. 1237-1252, April 2011.

[6] T. Kobaku, S. C. Patwardhan and V. Agarwal, "Experimental Evaluation of Internal Model Control Scheme on a DC–DC Boost Converter Exhibiting Non-minimum Phase Behavior," *IEEE Trans Power Electron.*, vol. 32, no. 11, pp. 8880-8891, Nov. 2017.

[7] Y. Li, T. Dragičević, S. Sahoo, Y. Zhang and F. Blaabjerg, "An Improved Model Predictive Control for DC-DC Boost Converter," *IEEE 13th International Symposium on Power Electronics for Distributed Generation Systems (PEDG)*, Kiel, Germany, 2022, pp. 1-6.

[8] F. A. Villarroel, J. R. Espinoza, M. A. Pérez, et al., "Stable shortest horizon FCS-MPC output voltage control in non-minimum phase boost-type converters Based on Input-State Linearization," *IEEE Trans. Energy Convers.*, vol. 36, no. 2, pp. 1378-1391, Jun. 2021.

[9] N. Guler, S. Biricik, S. Bayhan, and H. Komurcugil, "Model predictive control of DC-DC SEPIC converters with auto-tuning weighting factor," *IEEE Trans Ind. Electron.*, vol. 68, no. 10, pp. 9433–9443, Oct. 2021.

[10] L. Cheng, P. Acuna, R. P. Aguilera, et al., "Model predictive control for DC-DC boost converters with reduced-prediction horizon and constant switching frequency," *IEEE Trans. Power Electron.*, vol. 33, no. 10, pp. 9064-9075, Oct. 2018.

[11] Y. Li, S. Sahoo, T. Dragičević, Y. Zhang, F. Blaabjerg, "Stability Oriented Design of Model Predictive Control for DC/DC Boost Converter," *IEEE Trans Ind. Electron.*, Early access, doi 10.1109/TIE.2023.3247785.

[12] H. Zhang, Y. Li, R. Xie, J. Song, B. Liang and Y. Huangfu, "Adaptive Model Predictive Control of an Interleaved Boost Converter Using Real-Time Updated Model," *IEEE Trans. Power Electron.*, vol. 38, no. 2, pp. 1720-1731, Feb. 2023.

[13] W. Wu et al., "Data-Driven Iterative Learning Predictive Control for Power Converters," *IEEE Trans. Power Electron.*, vol. 37, no. 12, pp. 14028-14033, Dec. 2022.