A Novel Predictive control based Multi Input Multi Output Switched capacitor Step-Up Converter

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Abstract:

This study introduces the use of model predictive control (MPC) for the SRM Drive Application to improve the performance of pre-compensated power supplies, and in particular of DC–DC converters, by dynamically modifying their output voltage reference. The importance of developing controllers for pre-compensated converters is as compared to the PI controllers and predictive controllers. the proposed controller provides more advantages such as eliminate the extra modulation stages and improving the performance of steady and dynamic states. Moreover, proportional integral (PI) controllers design and their tuning parameters is more difficult to operate in a multi-input converter, compared to a single-input converter, since the behaviors of the multi input converter input currents are not independent. However, the MPC method will give a more ripple component result due to its inconstant switching frequency performance. Therefore, some modifications are required in the design procedure due to overcome the abovementioned problem of the conventional predictive scheme and improve the efficiency of the converter. Finally, the performance of the SRM drive based designed controller conventional predictive control method is verified through simulation in MATLAB environment.

1 Introduction

In the very last years, the continuously increasing tightening of efficiency and performance requirements enhanced several research branches in the control of power supplies [1–4]. Among them, model predictive control (MPC) saw a wide interest from both academy and industry [5–7]. MPC makes explicit use of the plant model to predict its future behavior, and it solves an optimal control problem at each sampling time [8]. The main aspects that favoured the interest of MPC in this field are the intuitive design and tuning of the controller, the enhanced performance and the availability of relatively accurate models for electrical devices [9–11]. Such highly requested features come at the cost of cumbersome online calculations, which have limited the spread of the method in fast-sampled systems. For these reasons, researchers have been encouraged in looking into efficient solutions for embedded MPC implementations [12], instead of using powerful embedded boards, such as field programmable arrays, that could not be available for such systems [13, 14].

Moreover, the very recent complexity certification of quadratic programming (QP) solvers is a step forward into safe implementation of embedded MPC [12]. When dealing with transistors-based devices, the literature splits into two branches. *Continuous Control Set* (CCS)-MPC takes control actions into a continuous set, which is usually the duty cycle of the pulse width modulation (PWM). *Finite control set* (FCS)-MPC exploits the discrete nature of power converters and takes action in a discrete control set namely the finite combinations of predicted switches' states [1, 10]. To deal with the computational load, explicit MPC is the preferred solution for CCS-MPC. It pre-solves the optimization problem through multi parametric quadratic programming (mpQP), and the implemented controller turns to be a piece wise affine function of parameters, easy to be applied online [15]. Explicit MPC has already been successfully used for power converters control [2, 16, 17]. However, it becomes impractical when the number of inputs or the prediction horizon is not small enough, due to the high-memory requirements. On the other hand, several algorithms have been proposed to efficiently implement FCSMPC, and to achieve long prediction horizons [10, 18]. The performances of CCS and FCS-MPC have been recently compared [19, 20]. FCS-MPC usually provides a faster response time than CCS-MPC. However, CCS-MPC decouples the switching frequency from the controller sampling time, and it operates the converter at a fixed frequency. For these reasons CCS-MPC is more often preferred in industrial applications.

The aim of this paper is to investigate MPC for precompensated Multi-Input DC–DC converters fed by SRM Drive. Following the idea of the reference governor (RG), this paper presents the design of an MPC loop that regulates a DC–DC converter while manipulating the reference of the actual primal controller [21–25]. Several engineering fields have already experimented the use of RG, such as automotive and robotics [26, 27]. However, the focus of the current research on power electronics' control algorithms, is almost completely based on replacing the standard controller. Only few recent attempts can be found where the modification of the reference is used to improve the transient response of standard controllers [28, 29]. Power conversion seems to be a field where the control of pre-compensated systems could find an important role. Indeed, very often there is no possibility to change the native controller, which is hard coded or even hardware-based [30]. The designer could also have the necessity to retain the primal controller due to stability and robustness certification .

Furthermore a double loop, multi-rate, control structure would permit to exploit the benefits of MPC with a slower sampling frequency, improving the feasibility of CCS-MPC in such fast sampling and computationally cheap systems. A preliminary study of the topic has been recently proposed by the authors in [32]. The controller designed here aims to regulate the reference of a voltage mode control (VMC) algorithm, that steers the output voltage of a synchronous buck DC–DC converter. Synchronous rectification is particularly attractive for efficiency optimisation with respect to the standard asynchronous rectification, and VMC is the simplest control technique for PWM converters, regulating the duty cycle of the gating PWM signal to track a desired output voltage VMC is implemented with a linear PI regulator. In the proposed work, the implemented MPC controller regulates the voltage reference solving an unconstrained optimal control problem at each sampling time. Unconstrained formulation is very cheap in terms of memory and computational load, and does not require neither an embedded solver or an explicit solution or a powerful board. The

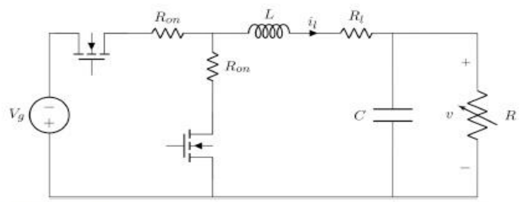

Fig. 1 *Electrical schematic of the synchronous DC–DC buck converter*

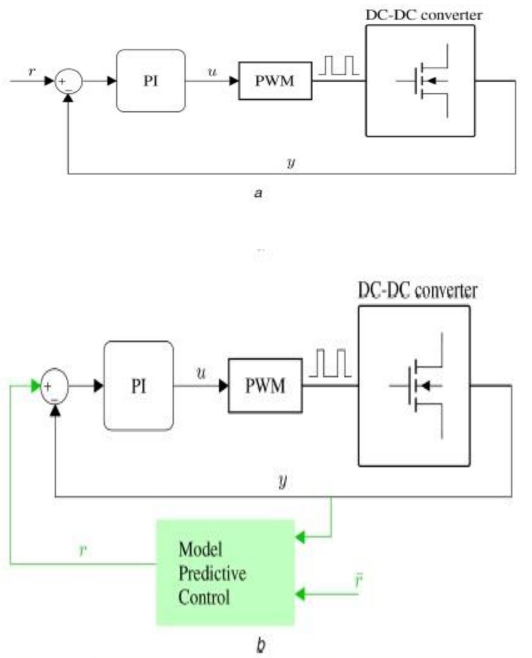

Fig. 2 *Block scheme of the standard VMC 2a, and the MPC applied to the pre-compensated system 2b. The added part is highlighted in green, the other remains unchanged*
(a) Standard VMC, *(b)* Proposed MPC-VMC

results show that, in the considered application, adding constraints is not necessary. However, a constrained formulation is a possible extension of the work, in particular considering current limits. Compared to the method in [28], the algorithm does not need any current sensor, leaving unaltered the hardware and software setup of the standard VMC. Furthermore, the use of MPC framework allows to exploit its intuitive tuning process, and opens the door to future input/output constrained implementations.

Recently, the employment of Multi input DC choppers in renewable energy systems are vast mentioned. Because of their many benefits like the lower variety of semiconductor switches, lower volume and price compared with the case of using two or a lot of single-input converters. In many previous works, several novel multi-input topologies with their corresponding benefits are planned However, using advanced management methods for these converters haven't been widely studied. the best and commonest management technique is to use PI controllers. Figure below depicts the management strategy for a multi-input converter utilizes the PI controllers. It ought to be noted that the performance of this strategy is simply optimized for one operative purpose. On the opposite hand, decisive the parameters of the PI controllers more tougher for a multi-input device, comparison to its single-input counterpart; since the behaviors of the input currents aren't self-sustaining.

The prophetic management technique is the modern strategy that is with success applied to power electronic converters because of blooming of quick microprocessors . This management strategy has been with success enforced for single-input DC-DC converters. Elimination of extra Modulation stages, easy sketch procedure and precise dynamic and steady-state responses are some benefits of the prophetic management strategy. However, the switching frequency is variable since no modulator is obtainable. This might cause some drawbacks like the presence of a high-frequency ripple element on the controlled variable waveform.

In this paper, a modified predictive controller is proposed and designed for the high-step multi-input switched-capacitor DC-DC converter in order to reduce the number of the switching actions. The designed controlled not only has the advantages of the conventional predictive controller, but also minimizes the switching losses and the efficiency is maximized as result.

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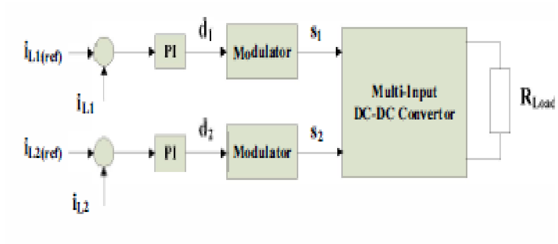


. Control scheme for a multi-input converter using PI controllers

In the normal operation of this converter, there must always be an interval in each switching period in which both switches are on. Moreover, at least one switch should be conducting at any instance. Therefore, this converter has three different operating modes. These modes are shown in Figure.

2 Multi-input switched-capacitor DC-DC converter

The topology of the multi-input switched-capacitor DC-DC converter is depicted in Fig. 2. The diode-capacitor stages are used to achieve a high step-up gain without needing very high duty ratio values.

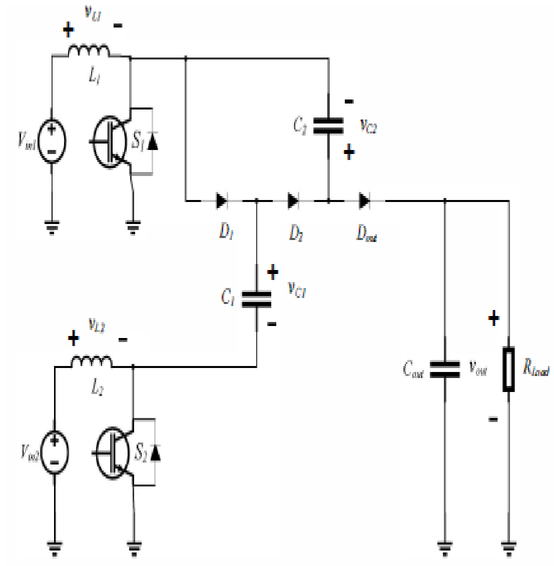
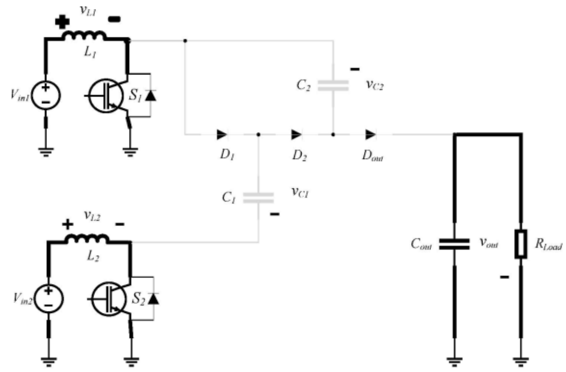


Fig. 3. Multi-input switched-capacitor DC-DC converter



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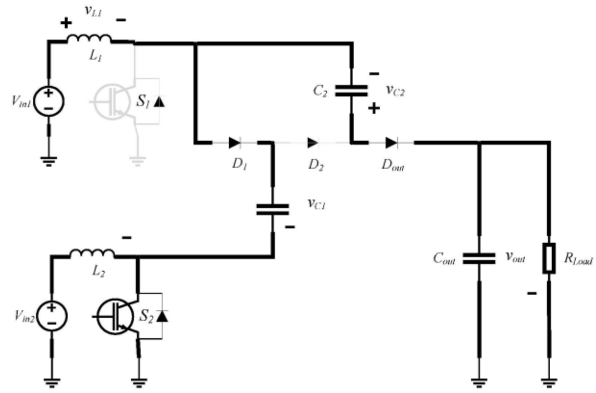

(b)

Different operating modes:

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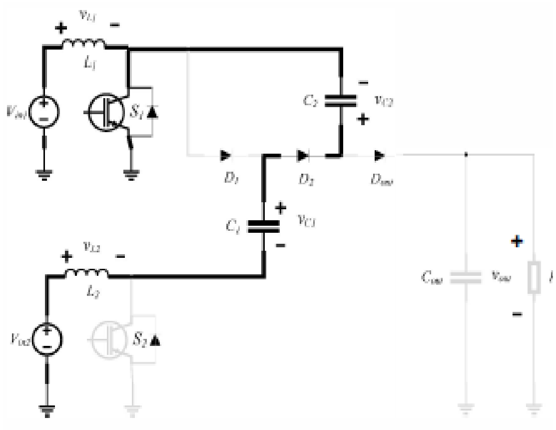

(c)

Fig. 4. Different operating modes of the converter; (a) sl=1 and s2=1; (b) SI=O and s2=1; (c) sl=1 and S2=0.

2.1 Mathematical model

DC–DC converters are switching systems due to the discrete input that assumes values in the set {0, 1}. This input corresponds to the on/off state of the switch. Although discrete actuation is a possible alternative, PWM converters are usually preferred in industrial applications. The main reason is the fixed switching frequency provided by the modulator which reduces the stress of the components. In addition, this permits to decouple switching and control frequencies, guaranteeing at the same time good ripple reduction and satisfactory sampling time. The model of PWM converters are averaged continuous model over a switching period . For the DC–DC buck converter considered in this paper, the averaged model is:

$\dot{x}(t) = Ax(t) + Bu(t)$ (1a)

$y(t) = Cx(t)$ (1b)

with $x \in \mathbb{R}^{n_x}$, $u \in \mathbb{R}^{n_u}$, $y \in \mathbb{R}^{n_y}$, and

$$A = \begin{bmatrix} -\frac{R_l + R_{on}}{L} & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{CR} \end{bmatrix}, \quad B = \begin{bmatrix} \frac{V_g}{L} \\ 0 \end{bmatrix}, \quad C = [0 \quad 1]. \qquad (2)$$

The states $x(t) = il(t)\ v(t)'$ are the inductor current and the output voltage, respectively, whereas the input $u(t) = d(t)$ is the duty cycle of the PWM and gets values in the range $\mathbb{R}[0, 1]$. L and C are the inductor and capacitor values, Rl and Ron the parasitic components of the inductor and switch, Vg is the input voltage, and R is the supplied load. Synchronous converters are usually controlled with a single input, with a master-slave technique that drives the two switches. In buck converters the primary switch is high-side, and directly driven by the PWM signal. The second transistor is lowside, and actuated by a complementary signal.

3 Predictive Control

Standard MPC solves a finite-horizon, optimal control problem based on a linear prediction model of the process [8, 15]. The interest in this technique is growing in power supplies. The ease in handling multivariable systems, imposing input/output constraints and the intuitive design process are some of the key factors that contributed to this interest [1, 18]. Indeed, the wide literature on the topic assessed MPC as one of the leading technology for the future of power

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electronics control [6]. However, two motivations can prevent the direct use of the MPC as a primal controller:

• a primal controller is already embedded into the physical system, either software or hardware, and cannot be modified;

• the dynamics of the system are too fast and a primal MPC is not feasible, thus a double, multi-rate, loop is preferred.

This paper addresses those problem, and presents the design of an MPC regulator for a pre-compensated power converter fed SRM Drive. The aim is to enhance the performance of the primal controller, without substituting it. It is assumed that a primal controller is already available and able to control the system properly.

In order to verify and compare the perfonnance of the designed predictive controller for /L = 0 (conventional controller) and /L =f:. 0 (modified controller), the studied converter and the controller are simulated in the MA TLAB/Simulink environment. The parameters used in the simulation are shown in table I.

TABLE I. SIMULATION PARAMETERS

Parameters	Values
V_{in1}	40 V
V_{in2}	60 V
L_1 and L_2	1 mH
C_1 and C_2	100 µF
C_{out}	500 µF
R_{Load}	100 Ω

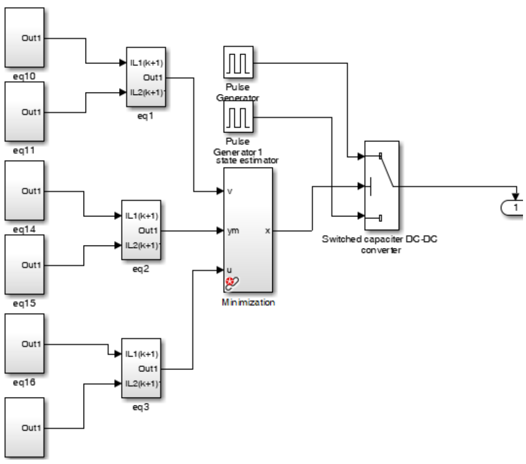

Figure.5. Block diagram of predictive controller design in MATLAB

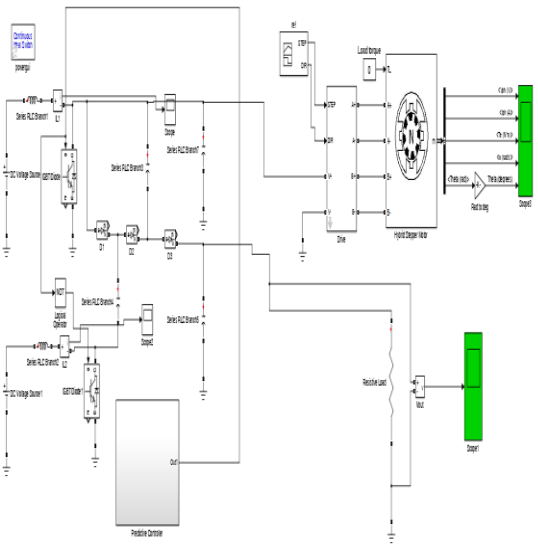

Figure. 6 Predictive control of multi input-multi output simulation Diagram With Load

4 Simulation results

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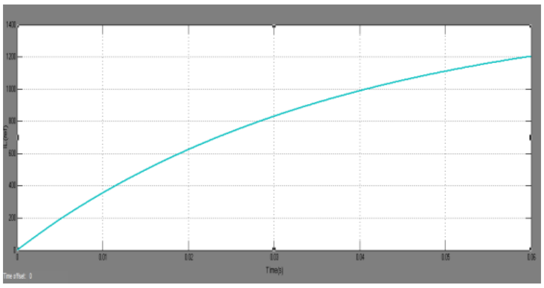

Figure.7 Simulation waveform of Inductor Current I_{L12}

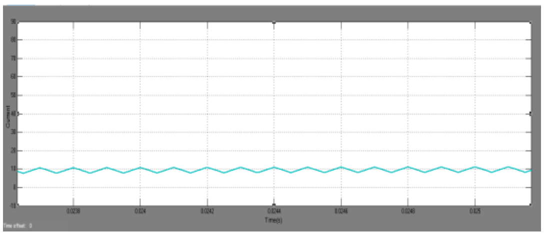

Figure.8 Simulation waveform of Inductor Current I_{L2}

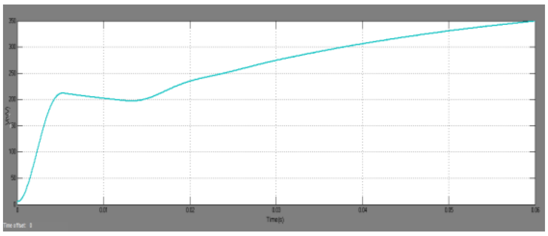

Figure.9 Resistive Load Output Voltage

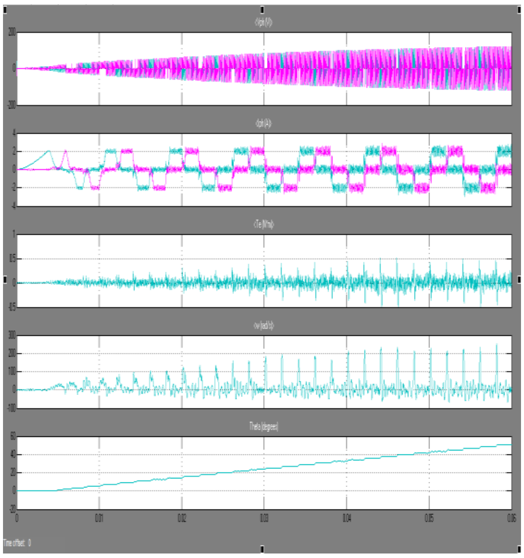

Figure.10 Stepper Motor Load Waveforms Vph, Iph, Torque, speed, angle

5 Conclusions

In this paper we have considered the use of MPC to regulate a precompensated power converter for SRM Load. With this strategy it is possible to improve performance of the control without modifying the primal regulator. Employing predictive control method has some notable advantages over using classical PI controllers such as simpler design procedure, elimination of additional modulation stages, and independence from the operating point. Variable switching frequency is the only drawback of predictive control method, which as seen from the simulation results, can add ripple components to the current waveforms and also lower the efficiency. Therefore, in order to overcome this problem, the cost function has been modified in a way that the switching frequency is minimized while maintaining the advantages of the predictive method at the same time. The simulation results revealed that the

modified predictive control method is able to minimize the current ripples by generating only a negligible steady-state error. Moreover, the proposed method will significantly increase the efficiency by reducing the noticeable switching losses generated by the conventional predictive method. Therefore, using the studied SRM Drive based converter with the suggested predictive control method can be an appropriate choice for renewable energy systems.

As a future research, a constrained formulation will be investigated, with the challenge of retaining a feasible implementation in low power applications.

6 References

[1] Vazquez, S., Leon, J., Franquelo, L., *et al.*: 'Model predictive control: a review of its applications in power electronics', *IEEE Ind. Electron. Mag.*, 2014, **8**, (1), pp. 16–31

[2] Mariethoz, S., Almer, S., Baja, M., *et al.*: 'Comparison of hybrid control techniques for buck and boost DC-DC converters', *IEEE Trans. Control Syst. Technol.*, 2010, **18**, (5), pp. 1126–1145

[3] Cimini, G., Ippoliti, G., Orlando, G., *et al.*: 'A unified observer for robust sensorless control of DC-DC converters', *Control Eng. Pract.*, 2017, **61**, pp. 21–27

[4] Cimini, G., Ippoliti, G., Orlando, G., *et al.*: 'Sensorless power factor control for mixed conduction mode boost converter using passivity-based control', *IET Power Electron.*, 2014, **7**, (12), pp. 2988–2995

[5] Bordons, C., Montero, C.: 'Basic principles of MPC for power converters: bridging the gap between theory and practice', *IEEE Ind. Electron. Mag.*, 2015, **9**, (3), pp. 31–43

[6] Kouro, S., Perez, M., Rodriguez, J., *et al.*: 'Model predictive control: MPC's role in the evolution of power electronics', *IEEE Ind. Electron. Mag.*, 2015, **9**, (4), pp. 8–21

[7] Scoltock, J., Geyer, T., Madawala, U.K.: 'Model predictive direct power control for grid-connected NPC converters', *IEEE Trans. Ind. Electron.*, 2015, **62**, (9), pp. 5319–5328

[8] Mayne, D.Q.: 'Model predictive control: recent developments and future promise', *Automatica*, 2014, **50**, (12), pp. 2967–2986

[9] Cortes, P., Kazmierkowski, M., Kennel, R., *et al.*: 'Predictive control in power electronics and drives', *IEEE Trans. Ind. Electron.*, 2008, **55**, (12), pp. 4312– 4324

[10] Rodriguez, J., Kazmierkowski, M., Espinoza, J., *et al.*: 'State of the art of finite control set model predictive control in power electronics', *IEEE Trans. Ind. Inf.*, 2013, **9**, (2), pp. 1003–1016

[11] Algreer, M., Armstrong, M., Giaouris, D.: 'Adaptive PD+I control of a switch-mode DC–DC power converter using a recursive FIR predictor', *IEEE Trans. Ind. Appl.*, 2011, **47**, (5), pp. 2135–2144

[12] Cimini, G., Bemporad, A.: 'Exact complexity certification of active-set

methods for quadratic programming', *IEEE Trans. Autom. Control*, 2017, **PP**, (99), pp. 1–1

[13] Cimini, G., Bernardini, D., Bemporad, A., *et al.*: 'Online model predictive torque control for permanent magnet synchronous Motors'. IEEE Int. Conf. on Industrial Technology (ICIT), 2015, March 2015, pp. 2308–2313

[14] Zhang, Z., Wang, F., Sun, T., *et al.*: 'FPGA based experimental investigation of a quasi-centralized dmpc scheme for a back-to-back converter', *IEEE Trans. Power Electron.*, 2015, **PP**, (99), pp. 1–1

[15] Bemporad, A., Morari, M., Dua, V., *et al.*: 'The explicit linear quadratic regulator for constrained systems', *Automatica*, 2002, **38**, (1), pp. 3–20

[16] Beccuti, A., Mariethoz, S., Cliquennois, S., *et al.*: 'Explicit model predictive control of DC-DC switched-mode power supplies with extended Kalman filtering', *IEEE Trans. Ind. Electron.*, 2009, **56**, (6), pp. 1864–1874

[17] Kim, S.K., Park, C.R., Kim, J.S., *et al.*: 'A stabilizing model predictive controller for voltage regulation of a DC/DC boost converter', *IEEE Trans. Control Syst. Technol.*, 2014, **22**, (5), pp. 2016–2023

[18] Karamanakos, P., Geyer, T., Oikonomou, N., *et al.*: 'Direct model predictive control: a review of strategies that achieve long prediction intervals for power electronics', *IEEE Ind. Electron. Mag.*, 2014, **8**, (1), pp. 32–43

[19] Preindl, M., Bolognani, S.: 'Comparison of direct and PWM model predictive control for power electronic and drive systems'. IEEE Twenty-Eighth Annual Applied Power Electronics Conf. and Exposition (APEC), 2013, March 2013, pp. 2526–2533

[20] Aguilera, R., Lezana, P., Quevedo, D.: 'Switched model predictive control for improved transient and steady-state performance', *IEEE Trans. Ind. Inf.*, 2015, **11**, (4), pp. 968–977

[21] Bemporad, A.: 'Reference governor for constrained nonlinear systems', *IEEE Trans. Autom. Control*, 1998, **43**, (3), pp. 415–419

[22] Garone, E., Nicotra, M.: 'Explicit reference governor for constrained nonlinear systems', *IEEE Trans. Autom. Control*, 2015, **PP**, (99), pp. 1–1

[23] Bemporad, A., Casavola, A., Mosca, E.: 'Nonlinear control of constrained linear systems via predictive reference management', *IEEE Trans. Autom. Control*, 1997, **42**, (3), pp. 340–349

[24] Barcelli, D., Bernardini, D., Bemporad, A.: 'Synthesis of networked switching linear decentralized controllers'. 49th IEEE Conf. on Decision and Control (CDC), December 2010, pp. 2480–2485

[25] Vermillion, C., Sun, J., Butts, K.: 'Predictive control allocation for a thermal

management system based on an inner loop reference model - design, analysis, and experimental results', *IEEE Trans. Control Syst. Technol.*, 2011, **19**, (4), pp. 772–781

[26] Oh, S.-R., Agrawal, S.: 'A reference governor-based controller for a cable robot under input constraints', *IEEE Trans. Control Syst. Technol.*, 2005, **13**, (4), pp. 639–645

[27] Jade, S., Hellstrom, E., Larimore, J., *et al.*: 'Reference governor for load control in a multicylinder recompression HCCI engine', *IEEE Trans. Control Syst. Technol.*, 2014, **22**, (4), pp. 1408–1421

[28] Kurokawa, F., Sakemi, J., Yamanishi, A., *et al.*: 'A new quick transient response digital control dc-dc converter with smart bias function'. 2011 IEEE 33rd Int. Telecommunications Energy Conf. (INTELEC), October 2011, pp.1–7

[29] Kurokawa, F., Yamanishi, A., Hirotaki, S.: 'A reference modification model digitally controlled DC-DC converter for improvement of transient response', *IEEE Trans. Power Electron.*, 2016, **31**, (1), pp. 871–883

[30] Kogiso, K., Hirata, K.: 'Reference governor for constrained systems with time-varying references', *Robot. Auton. Syst.*, 2009, **57**, (3), pp. 289–295.

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