الجمهورية الديمقراطية الشعبية الجزائرية

République Algérienne Démocratique et Populaire

Ministère de l'Enseignement Supérieur
et de la Recherche Scientifique
Ecole Supérieure des Sciences Appliquées
d'Alger

وزارة التعليم العالي والبحث العلمي
المدرسة العليا في العلوم التطبيقية بالجزائر

Département du second cycle

Mémoire de Fin d'Etudes

En vue de l'obtention du diplôme de MASTER

Filière : **Electrotechnique**

Spécialité : **Traction électrique**

Thème :

Model Predictive Control : State of the Art

Présenté par : Bey Anis Samy

Encadré (e) par : Dr. BENACHOUR Ali
Co-encadré(e) par : Dr. Dali Ali

Soutenu le : 03/07/2022

Devant le jury composé de :

M	**ROUBACHE Lazhar**	**Président (e)**
M	**HAMACHE Amar**	**Examinateur (rice)**
M	**BENACHOUR Ali**	**Encadreur (e)**
M	**DALI Ali**	**Co-Encadreur (e)**

Monôme N° : 15 /Master /TR/ 2021-2022

ملخص:

الغرض من هذا الموضوع هو عمل توليف ببليوغرافي وحالة فنية في التحكم التنبئي على أساس نموذج MPC بالإضافة إلى تشغيله وتطويره على مر السنين.

الكلمات الرئيسية: التحكم في التنبؤات القائمة على النماذج ، والذكاء الاصطناعي ، ووقت الحساب.

Abstact

The purpose of this topic is to make a bibliographical synthesis and a state of the art about the predictive control model-based as well as its operations and its developments over the years.

Keywords: model-based predictive control (MPC), artificial intelligence, computation time.

Resumé

Le but de ce sujet est de faire une synthèse bibliographique et un etat de l'art sur la commande prédictive à base du modèle MPC ainsi que son fonctionnement et son developpement au fil des années.

Mots clés : commande prédictive à base du modèle (MPC), intelligence artificielle, temps de calcul.

Acknowledgment

I would like to express my sincere and deepest appreciation to my advisor Dr. BENACHOUR Ali and to my co-advisor Dr. DALI Ali, for their help and continuous invaluable support, for their patience, and their infinite constructive guidance and advices. For their motivation and their belief in me and the final fruit we have been working on.

I also like to extent my heartfelt thanks to examiners for proofreading and examining my thesis. I would like to thank Dr. ROUBACHE Lazhar who give me the honor of chairing the committee. My thanks also goes to the members of the jury who gave me the honor of participating in the committee.

I am also grateful to the staff at the Higher School of Applied Sciences of Algiers especially those from the Electrical Engineering department especially.

My extended deep thanks to MEKHILEF Aymen, BOUBERGOUG Aya, HATTABI Intissar for their help during this work. It would not possible to conclude this work. Without mentioning our families and their unconditional love and support, our friends and their meaningful backup, and everyone who has believed in me.

Dedication

First of all , I would like to thank all the persons who never stopped to support me, to believe in me, to watch over my success from a very young age, to whom I owe what I became today, and what I will become in the future, my family.

I dedicate this work
To my borther OMAR who are always there for me, whom I hope to be proud of me.

To my Grandmother, May Allah prolongs her life and grants her health.
To my uncle AMINE, my confident, the person who always takes care of me, may god bless him.

To my confident friends SAMIA and HANANE.
To my childhood friend SAMY .
To my best friend Amel who never stopped believing in me and for her precious help as partner.
To My friends Yahia and Juba.

SAMY

Table of contents

List of figures

List of figures

State of the art

Improvement of model predictive control

Introduction:

The use of power converters has become very popular in the recent decade with a wide range of applications, including drives, enery conversion, traction, and distributed generation. The control of power converters has been extensively studied, and new control schemes are presented every year, power electronics circuits have proved indispensable in many areas because they convert electrical power from one form to another, such as ac-dc, dc-dc, dc-ac, or even ac-ac with a variable output magnitude and frequency [1].

Many control strategies for power electronics have been proposed that have been shown to be reasonably effective. Mainly, these are strategies based on linear controllers combined with nonlinear techniques, such as pulse width modulation (PWM). However, controllers of this type are usually tuned to achieve optimal performance only over a narrow operating range; outside this range the performance is significantly deteriorated. Therefore, the problems associated with many applications and their closed-loop controlled performance still poses theoretical and practical challenges. Furthermore, the advent of new applications leads to the need for new control approaches that will meet the increasingly demanding performance requirements.

A control algorithm that has been recently gaining more popularity in the field of power electronics is model predictive control (MPC) [2, 3]. This control method, which has been successfully used in the process industry since the 1970s, has attracted the interest and attention of research and academic communities due to its numerous advantageous features, such as design simplicity, explicit inclusion of design criteria and restrictions, fast dynamics and inherent robustness. In addition, the emergence of fast microprocessors has increasingly enabled successful implementation [7, 6, 5, 4].

The aim of this thesis is to summarize the current state and analyze the most recent advances in the application and Improvement methods of MPC for power converters and drives. Thus, the work presents the current advances and challenges of MPC for power electronic applications and addresses possible future trends.

I.1 Principal Work of Wodel Predictive Control

Predictive control has been considered as a part of optimal control theory since 1960s [6]. The model predictive control (MPC), a branch of predictive control, has found growing applications in motor drives and power electronics MPC implies the idea of employing a model of a plant under control to predict the future behavior of the model control system's output. The prediction provides the capability to solve optimal control problems for minimizing the tracking error of the predicted output with respect to a desired reference [7]. During the last two decades, several reviews have been conducted of the MPC literature from various points of view. One of the earliest survey studies reviewed MPC theory and design techniques[8]. A part of that review deals with the robustness issues, indicating that this has been an important topic since the very beginning. Robust MPC theory and implementation methods are presented and surveyed in[8], [9], The theory allows for the systematic handling of system uncertainties. The early approach of robust MPC is based on min-max optimal control problem formulations in which the controller acts according to the worst-case evaluations of the cost function.

The application of MPC method in its different forms is also addressed in the field of drives and power electronics, including active filters, distributed generation, and renewable energy, …etc.

In general, one could mention as the basic "components" of MPC the following:

1. Mathematical model of the controlled plant: The mathematical model of the system under investigation is required for the calculation of the evolution of the system states over time.
2. Optimal control problem: An objective function that embodies the control objectives is formulated. The optimization problem is solved, and the optimal sequence of control actions that results in the best behavior of the plant over the prediction horizon is derived. Note that prediction horizon is the time interval in which the control actions are planned, and the behavior of the plant is predicted.
3. Receding horizon policy: According to the receding horizon policy, only the first element of the optimal sequence of the control inputs is applied to the plant. The remaining elements are discarded, the prediction horizon is shifted forward by one sampling instant, and the optimization procedure is repeated.

Predictive control covers a very wide class of controllers that have found rather recent application in power converters. A classification for different predictive control methods is shown in the following Figure:

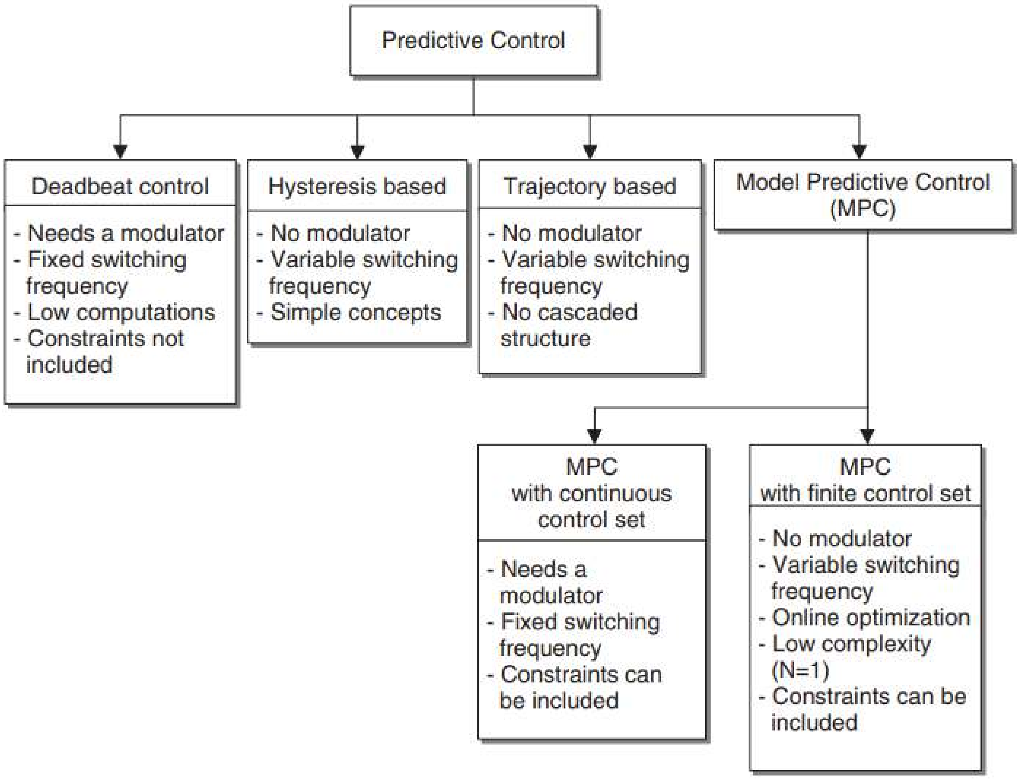


Figure I- 1: Classification of predictive control methods in power electronics

I.2 Development of MPC (History)

According to authors research, the MPC was the first used in industry such as oil and petrochemical industries, which dates back to the 1950s as a computer based supervisory control. At that time, MPC was a promising control strategy yet it wasn't widely embraced by other process industries due to the computational power needed for the MPC until the mid-1970s, when several other techniques were introduced like: Model Heuristic Predictive Control (MHPC) and Dynamic Matrix Control (DMC). These two control algorithms were developed into Generalized Predictive Control (GPC) which is more robust compared to the MHPC and DMC [10].

In the second decade of the MPC development, during the late 1980s, researchers founded a theoretical approach for the MPC: the discrete-time state-space representation model:

$$\begin{cases} x[i+1] = Ax[i] + Bu[i] \\ y[i+1] = Cx[i] + Du[i] \end{cases}$$

During this decade, researchers showed interest in studying the stability of the MPC for the first time. Which can be proved by considering the cost function of the MPC as a Lyapunov function. The cost function is introduced in the next paragraph

I.3 MPC Strategy

The methodology of all the controllers belonging to the MPC family is characterized by the following strategy, represented in figure

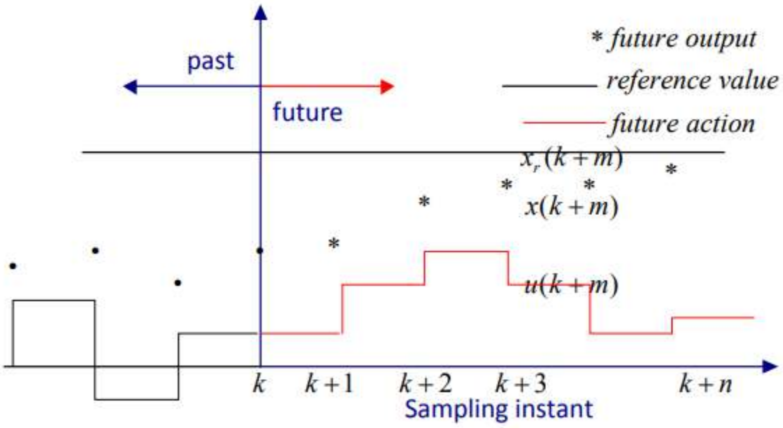


Figure I- 2: Working principle of MPC

The methodology of all the controllers belonging to the MPC family is characterized by the following strategy, represented in figure

$$\hat{x}(k+1) = Ax(k) + Bu(k)$$
$$y(k) = Cx(k) + Du(k)$$

Where $x(k)$ and $\hat{x}(k+1)$ are the system state vectors at the current and next instants, respectively. Also $u(k)$ and $y(k)$ are input and output vectors, respectively, at the current instant. A, B, C, and D are the system input, output and disturbance matrix, respectively.

An objective function J which is a function of system states and inputs, is defined to formulate the system's desired performance as:

$$J = f\big(x(k), u(k), \dots \dots \dots .., u(k+N)\big)$$

Where N is a postitive number known as the prediction horizon and is the number of future instances over which the control can predict the system's performance. The vector $u(k+N)$ is the system input at the instance $k+N$ .The sequence of the inputs prior to $u(k+N)$ is also included in J, as shown in figure below:

I.4 MPC's Elements

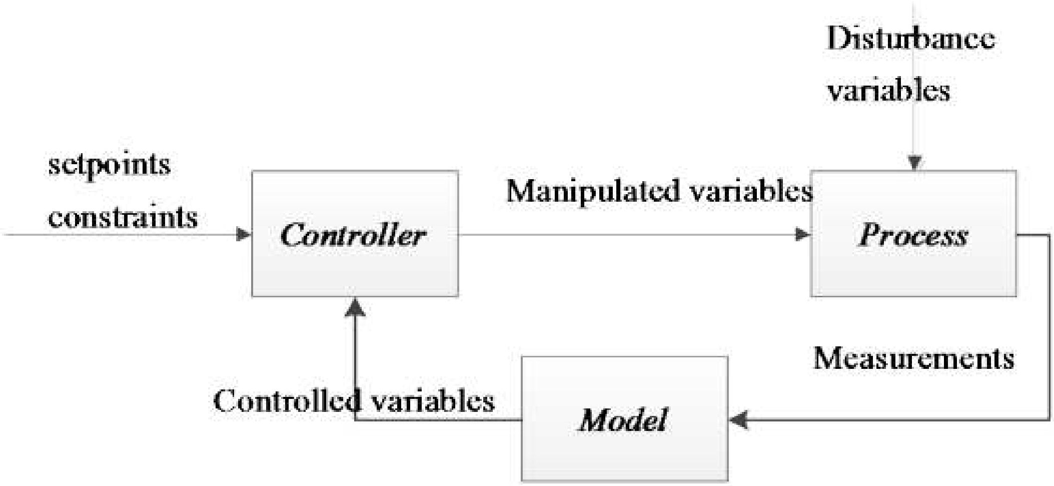


Figure I- 3 : Basic structure of MPC

All the MPC algorithms possess common elements and different options can be chosen for each one of these elements giving rise to different algorithms. These elements are:

- Prediction Model
- Objective Function
- Obtaining the control law

I.5 Prediction Model

The model is the corner-stone of MPC [22]; a complete design should include the necessary mechanisms for obtaining the best possible model, which should be complete enough to fully capture the process dynamics and should also be capable of allowing the predictions to be calculated and at the same time, to be intuitive and to permit theoretic analysis.

Practically every possible form of modeling a process appears in a given MPC formulation, the following being the most commonly used:

- Transfer function .
- State space.

I.6 Objective Function

The various MPC algorithms propose different cost functions for obtaining the control law. The cost function definition is one of the most important stages in the design of an MPC, since it allows not only to select the control objectives of the application, but also to include any required constraints that represents the desired behavior of the system [23]. This function considers the references, future states (or predicted states), and future actuations. In case of a multivariable system, the cost function may be written as

$$J=\sum_{i}^{n} \lambda_i \left| x_i^* - x_i^p \right|$$

Where:

n: is the number of controlled variables

x_i : is the controlled variable

x_i^* : is the reference value of the controlled variable

x_i^p: is the predicted value of the controlled variable

λ_i: is the weighting factor

The weighting factor allows for adjusting the importance of each controlled variable according to its priority in the scope statement. The selected actuation is the one that minimizes the cost function, it is stored so that it can be applied to the converter in the upcoming sampling period [24]

I.7 Obtaining the control law

In order to obtain values u (t + k ∣ t) it is necessary to minimize functional *J*. To do this the values of the predicted outputs y(t + k ∣ t) are calculated in function of past values of inputs and outputs and of future control signals, making use of the model chosen and substituted in the cost function, obtaining an expression whose minimization leads. An analytical solution can be obtained for the quadratic criterion if the model is linear and there are not constraints, otherwise an iterative method of optimization should be used [44].

If the system is not linear but nonlinear ,we can use linear MPC and still benefit from the proprieties of the convex optimization problem , the available method to use this case are the adaptive and gain scheduled MPC , the way these controllers deal with a nonlinear system is based on linearization. If the system is nonlinear and that cannot be approximated well then we have to use nonlinear MPC, this method is the most powerful on as, it uses the most powerful on as, it uses the most accurate representation of plant.

II.1Application of MPC

MPC is able to achieve high-performance results in a wide range of applications. For decades, it has successfully broadened its applications from chemical processes to renewable energy, power converters and motor drives.

The application of MPC on power converters has extended to grid-connected converters, for instance: flexible AC transmission systems (FACTS), static synchronous compensators (STATCOMs), active power filters (APFs),unified power flow controller (UPFC)or a converter to control the torque and/or speed of awind turbine for grid integration of renewable energies[25]

Model predictive controlled active-front-end (AFE) rectifiers for energy storage systems, which has been increasingly applied in power distribution sectors and in renewable energy sources[26], where the main objective of the control strategy is to regulate the output voltage to a given reference [25].In[26]the authors performed a comparison demonstrating thatthe MPC controller is more effective than voltage oriented control based PWM (VOC-based-PWM) AFE rectifiers.The structure used for the control of an AFE is cascaded, one outer control loop for regulating the DC-link voltage and one inner control loop for pursuing the reference current and power [25]. Model predictive controlled AFE are used for either controlling the instantaneous active and reactive power, hence the nomenclature predictive direct power control (P-DPC), or for controlling the grid currents[29]. The most used control scheme of a Model predictive controlled AFE is P-DPC uses an external modulatorthus it has a fixed switching frequency which means that grid current harmonic spectrum is concentrated around the switching frequency minimizing the cost of the output filter [25]

Another fundamental grid-connected converter is the APF, which is basically a voltage-source inverter whose DC-link is connected to a capacitor’s bank[25],[27]. It is for compensating the unbalanced, reactive, and harmonic components of the currents drawn by any load[27]. In[28]the authors investigate the application of MPC to shunt APF. The proposed approach does not require grid synchronization or PWM schemes and provides a single control loop structure enhancing the dynamic performance which is useful for satisfying the dynamic of modern-day smart grids.

MPC has also been applied to Selective Harmonic Elimination (SHE) [30], the technique is called MPC-SHE and its cost function is formulated in a way to follow the voltage reference, to eliminate low-order harmonics, and to reduce switching losses where a sliding discrete Fourier transform is used [25].

For motor drive applications of the MPC, the measured variables are usually the current and the mechanical speed. And the other variables such as torque, stator or rotor flux are estimated using estimators or the mathematical model of the machine [29]. Estimators are also useful for sensor less MPC [9].

The controlled variables of a predictive torque control (PTC) of an IMC fed induction machine are the torque and the stator flux [18].And given the possibility to adjust the importance or the priority of a variable by adjusting the weighting factors in the cost function, the authors of [31] have been able to reduce the torque ripples of an IMC fed induction machine by optimizing the weighting factor

II.2 MPC in power electronics

Variants of MPC have thenceforth been developed and implemented in power converters and used in applications such as electrical drives, static synchronous compensators (STAT-COMs), high voltage dc (HVDC) systems, flexible ac transmission systems (FACTS), and uninterruptible power supplies (UPS), to name a few [10],[11]

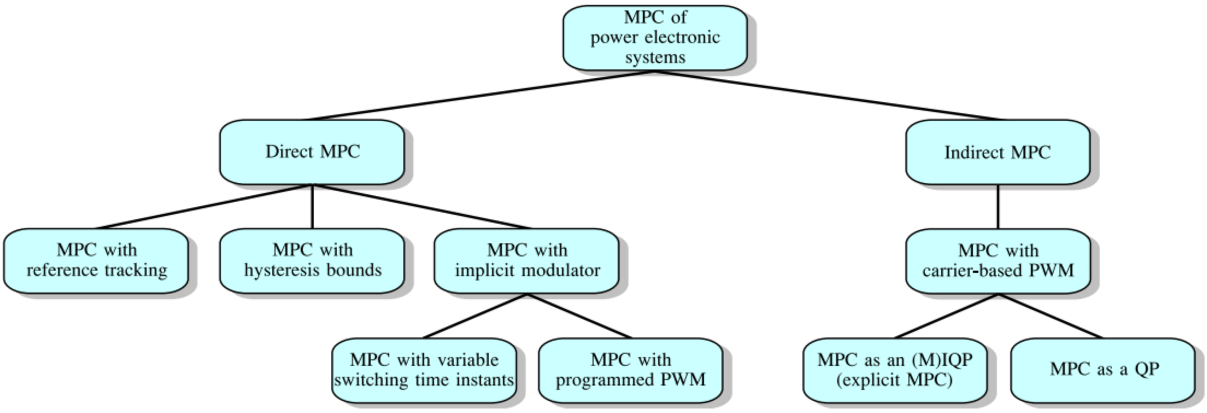
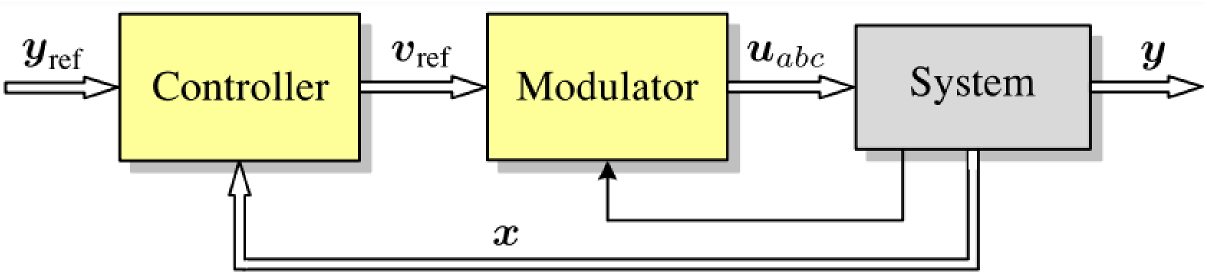
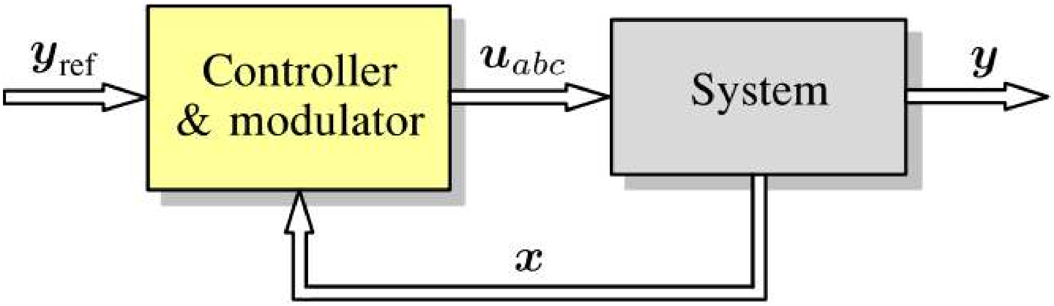


Figure I- 4 : MPC of power electronic systems.

MPC schemes for power electronics can be classified into two main categories depending on whether they employ a separate modulator or not. In the former case, MPC is implemented as an indirect controller, i.e., the controller computes the modulating signal/duty ratio which is fed into a modulator for generation of the switching commands, see Figure-14 (a). Hence, the control action is a real-valued vector. On the other hand, when MPC is designed as a direct controller, the control and modulation problems are formulated and solved in one computational stage, thus, not requiring a dedicated modulator, See Figure I-14 (b). Consequently, the elements of the control input vector are the switching signals, implying that it is an integer vector



(a) Indirect control scheme



(a) Direct control scheme

Figure I- 5 : Main controller structures of MPC

The aforementioned MPC algorithms can be further divided into smaller groups as shown in Figure I-13 Direct MPC-based schemes include controllers with reference tracking, hysteresis bounds and implicit modulator. Direct MPC with reference tracking, also known as finite control set MPC (FCS-MPC),is the most favored method in academia due to its well-reported advantages such as its intuitive design procedure and straightforward implementation [12],[13]-[14]. The aim is to achieve regulation of the output variables along their reference trajectories by manipulating the converter switches, and thus directly affecting their evolution. This variant of direct MPC, however, comes with pronounced computational complexity which can potentially lead to computationally intractable optimization problems. Moreover, researchers often-knowingly or not—resort to design simplifications that detract from its effectiveness and result in inferior performance compared with conventional control techniques, see the paper [15].

Direct MPC with hysteresis bounds was the first rudimentary version of this type of controllers developed for power electronic converters [16],[17]-[18]. This algorithm employs hysteresis bounds within the variables of interest, such as the stator currents, or the electromagnetic torque and stator flux magnitude of a machine, need to be constrained. Later, more sophisticated derivatives were devised which adopt a variety optimization criteria and/or nontrivial prediction horizons [19]-[20]. Moreover, the versatility of the method in discussion allowed for different types of hysteresis bounds that affect the system performance in terms of, e.g. harmonic distortions or switching losses [17],[21],[22].

Finally, the third group of direct MPC strategies can be further divided into two subgroups. The first one includes methods that manipulate not only the switching signals, but also their application time in an attempt to emulate the behavior of pulse width modulation (PWM) techniques. More specifically, these methods—and in contrast to the aforementioned direct MPC strategies—introduce the concept of variable switching time instants by changing the state of the switches at any time instant within the sampling interval. This is done by computing both the optimal switch positions and the associated duty cycles [23]-[24]. In doing so, higher granularity of switching is introduced enabling the reduction of the harmonic distortion in the variables of concert. Moreover, some of these methods achieve operation of the power converter at a fixed switching frequency, thus resulting in deterministic switching losses.[25],[24],[26],[27]-[28].

The second group consists of direct MPC methods that are combined with programmed PWM [29], i.e., modulation methods that forgo a fixed modulation interval. The switching pattern and the switching instants are computed offline based on some optimization criteria, such as minimization of the current total harmonic distortion (THD) and/or the elimination of specific harmonic. Programmed PWM is implemented in the form of selective harmonic elimination (SHE) [30],[31] , or optimized pulse patterns (OPPs) [32],[33]. The idea of manipulation of the switching instants of OPPs in a predictive fashion was introduced in [34],[35] and [36],[36] for stator current and stator flux reference trajectory tracking, respectively. These methods, however, lack the recording horizon policy and do not distinguish between the fundamental and the ripple components thus complicating the observer design [37]. To address these issues, more sophisticated MPC algorithms for the control of OPPs deemed necessary, leading to the methods presented. Moreover, SHE with MPC is presented, e.g., in [38],[39]. Owing to the nature of the programmed modulation methods these MPC-based strategies achieve very low harmonic distortions, but they are fairly elaborate since fast closed-loop control is challenging.

II.3 The major problem of the MPC

The Model Predictive Control (MPC) is a well-established technique for process control that has been applied to electrical systems, so after the three decades of the gradual development, so what remains now? [45]

At present, the MPC suffer from many problems, such as the lack of systematic handling of uncertainty. Therefore, it is necessary to improve the prediction accuracy for mismatched prediction models. The other problem is how to design the cost functions and the weight coefficients [46] [47] .One of the other drawback of MPC is that it requires the optimization problem to be solved online

All this makes the existing MPC algorithms suffer from a major challenge: relatively low computation efficiency [48] and huge amount of real-time calculations [13].

II.4 Drawback of MPC

An analysis of MPC algorithms when applied to power converters and drives reveals that the key elements for any MPC strategy are the prediction model, cost function and optimization algorithm. Research efforts have been made in all of these topics, and several problems and limitations have been found. The existing research works have solved some of them while others are still open issues to be investigated. Among the most important studied aspects are [32]:

- Prediction model discretization.
- Frequency spectrum shaping.
- Cost function design.
- Reduction of computational cost.
- Increasing prediction and control horizon.
- Stability and system performance design.

II.5 Improvement of MPC Control

One of the challenges that still needs to be overcome in order to im prove the performance of the model predictive control (MPC) is its maintenance. Re-identification of the process is one of the best options available to update the internal model of the MPC, in order to increase the production and improve efficiency. However, re-identification is costly Researchers have proposed two different methods able to detect plant mismatch through partial correlation analysis. Using these techniques, instead of re-identifying all the sub-models in the process, only a few inputs with significant mismatch would have to be perturbed and only the degraded portion of the model would be up dated. Nevertheless, there isn't enough information and analysis about the influence of the choice of the structures for identification on partial correlation results.

In [33] a Carlsson method have been demonstrate which is a particular solution of the Badwe et al. method, when the models used on the identification process are FIR structures. Moreover, some other types of structures were analyzed in order to check if they are suitable for the partial correlation procedure to detect plant mismatches.

In [34] , Mr. SangshinKwak and al studied the possibility of reducing the MPC incertitude by proposing predictive-control-based direct power control (DPC) with an adaptive online parameter identification technique for AC-DC active front ends (AFEs). This approach calculates the input inductance and resistance in the model parameters using the sampled input currents and input voltages every sampling period based on least-squares estimation. Therefore, the AFE generates sinusoidal input currents , and it mitigate performance degradation resulting from the model uncertainty of the MPC

In order to solve the parameter dependence problem in model predictive control, an improved model predictive current control (MPCC) method based on the incremental model for surface-mounted permanent magnet synchronous motor (SPMSM) drives is proposed in [35 where the results of simulation show that it can effectively reduce the parameter sensitivity of the MPCC. Firstly, an analysis of the parameter sensitivity of conventional MPCC method is established. Then incremental prediction model is introduced to eliminate the use of permanent magnetic flux linkage in prediction model. Therefore, in order to improve the anti-parameter-disturbance capability of the MPCC method, an inductance disturbance controller, is presented to update accurate inductance information for the whole control system in real time.

II.6 Conclusion

Model Predictive Control (MPC) is a very attractive solution for controlling power electronic applications. This documents describe the current state of MPC for power converters and drive, including recent developments and trends. The working principle of MPC has been verified, and it can be concluded that the implementation of MPC depends on three keys elements, namely the prediction model, the cost function and the optimization algorithm. Several issues related to these topics have been investigated by the research and industrial communities. The most relevant issues are cost function selection, weighting factor design, reduction of the computational cost and the extension of prediction horizons.

This paper summarizes various solutions of these problems proposed in the literature and presents the main progress of MPC for power converters and drivers.

References

[1] N. Mohan, T. M. Undeland, and W. P. Robbins. Power Electronics: Converters, Applications and Design. Wiley, Hoboken, NJ, 3rd edition, 2003.

[2] J. M. Maciejowski. Predictive Control with Constraints. Prentice-Hall, Englewood Cliffs, NJ, 2002

[3] J. B. Rawlings and D. Q. Mayne. Model Predictive Control: Theory and Design. Nob Hill, Madison, WI, 2009.

[4] A. Linder, R. Kanchan, R. Kennel, and P. Stolze. Model-based Predictive Control of Electric Drives. Cuvillier Verlag, G¨ottingen, Germany, 2010.

[5] S. Kouro, P. Cort´es, R. Vargas, U. Ammann, and J. Rodr´ıguez. Model predictive control—A simple and powerful method to control power converters. IEEE Trans. Ind. Electron., 56(6):1826–1838, Jun. 2009

[6] T. Geyer. Low Complexity Model Predictive Control in Power Electronics and Power Systems. PhD thesis, Autom. Control Lab. ETH Zurich, Zurich, Switzerland, 2005.

[7] L. G. Franquelo, J. Rodr´ıguez, J. I. Leon, S. Kouro, R. Portillo, and M. A. M. Prats. The age of multilevel converters arrives. IEEE Ind. Electron. Mag., 2(2):28–39, Jun. 2008.

[8] J. Zhang, L. Li, et D. G. Dorrell, « Control and applications of direct matrix converters: A review », *Chin. J. Electr. Eng.*, vol. 4, nº 2, p. 18□27, 2018.

[9] S. Ansari et A. Chandel, « Simulation based comprehensive analysis of direct and indirect matrix converter fed asynchronous motor drive », in *2017 4th IEEE Uttar Pradesh Section International Conference on Electrical, Computer and Electronics (UPCON)*, oct. 2017, p. 9□15, doi: 10.1109/UPCON.2017.8251014.

[10] O. Abdel-Rahim, H. Abu-Rub, A. Iqbal, et A. Kouzou, « Five-to-three phase direct matrix converter with model predictive control », in *4th International Conference on Power Engineering, Energy and Electrical Drives*, mai 2013, p. 204□208, doi: 10.1109/PowerEng.2013.6635607

[12]L. Huber et D. Borojevic, « Space vector modulated three-phase to three-phase matrix converter with input power factor correction », *IEEE Trans. Ind. Appl.*, vol. 31, nº 6, p. 1234□1246, 1995.

[13] M. Hamouda, H. F. Blanchette, et K. Al-Haddad, « Indirect Matrix Converters' Enhanced Commutation Method », *IEEE Trans. Ind. Electron.*, vol. 62, nº 2, p. 671□679, févr. 2015, doi: 10.1109/TIE.2014.2341583.

[14] C. Klumpner, « An indirect matrix converter with a cost effective protection and control », in *2005 European Conference on Power Electronics and Applications*, sept. 2005, p. 11 pp.-P.11, doi: 10.1109/EPE.2005.219558.

[15] H. J. Cha, « Analysis and design of matrix converters for adjustable speed drives and distributed power sources », 2004.

[16] M. Hosseini Abardeh et R. Ghazi, « A Dynamic Model for Direct and Indirect Matrix Converters », *Adv. Power Electron.*, vol. 2014, p. 864203, avr. 2014, doi: 10.1155/2014/864203

[17] L. Rmili, S. Rahmani, H. Vahedi, et K. Al-Haddad, « Comprehensive analysis of Matrix Converters: Indirect topology », in *2014 15th International Conference on Sciences and Techniques of Automatic Control and Computer Engineering (STA)*, déc. 2014, p. 679684, doi: 10.1109/STA.2014.7086728.

[18] Yong Shi, Xu Yang, Qun He, et Zhaoan Wang, « Research on a novel capacitor clamped multilevel matrix converter », *IEEE Trans. Power Electron.*, vol. 20, nº 5, p. 10551065, sept. 2005, doi: 10.1109/TPEL.2005.854027.

[19] P. C. Loh, F. Blaabjerg, F. Gao, A. Baby, et D. A. C. Tan, « Pulsewidth Modulation of Neutral-Point-Clamped Indirect Matrix Converter », *IEEE Trans. Ind. Appl.*, vol. 44, nº 6, p. 18051814, déc. 2008, doi: 10.1109/TIA.2008.2006321.

[20] Y. Sun, W. Xiong, M. Su, X. Li, H. Dan, et J. Yang, « Topology and Modulation for a New Multilevel Diode-Clamped Matrix Converter », *IEEE Trans. Power Electron.*, vol. 29, nº 12, p. 63526360, déc. 2014, doi: 10.1109/TPEL.2014.2305711.

[21] S. Vazquez, J. Rodriguez, M. Rivera, L. G. Franquelo, et M. Norambuena, « Model Predictive Control for Power Converters and Drives: Advances and Trends », *IEEE Trans. Ind. Electron.*, vol. 64, nº 2, p. 935947, févr. 2017, doi: 10.1109/TIE.2016.2625238.

[22] « Model Predictive Control by E. F. Camacho, C. Bordons (z-lib.org).pdf ». .

[23] J. Rodriguez *et al.*, « State of the art of finite control set model predictive control in power electronics », *IEEE Trans. Ind. Inform.*, vol. 9, nº 2, p. 10031016, 2012.

[24] S. Vazquez *et al.*, « Model predictive control: A review of its applications in power electronics », *IEEE Ind. Electron. Mag.*, vol. 8, nº 1, p. 1631, 2014.

[25] S. Vazquez *et al.*, “Model Predictive Control: A Review of Its Applications in Power Electronics,” *IEEE Industrial Electronics Magazine*, vol. 8, no. 1, pp. 16–31, Mar. 2014, doi: 10.1109/MIE.2013.2290138.

[26] M. P. Akter, S. Mekhilef, N. M. L. Tan, and H. Akagi, “Stability and performance investigations of model predictive controlled active-front-end (AFE) rectifiers for energy storage systems,” *Journal of Power Electronics*, vol. 15, no. 1, pp. 202–215, 2015.

[27] H. Akagi, A. Nabae, and S. Atoh, “Control Strategy of Active Power Filters Using Multiple Voltage-Source PWM Converters,” *IEEE Transactions on Industry Applications*, vol. IA-22, no. 3, pp. 460–465, May 1986, doi: 10.1109/TIA.1986.4504743.

[28] P. Zanchetta, P. Cortes, M. Perez, J. Rodriguez, and C. Silva, “Finite States Model Predictive Control for Shunt Active Filters,” in *IECON 2011 - 37th Annual Conference of the IEEE Industrial Electronics Society*, Nov. 2011, pp. 581–586, doi: 10.1109/IECON.2011.6119375.

[29] J. Holtz and U. Boelkens, “Direct frequency convertor with sinusoidal line currents for speed-variable AC motors,” *IEEE Transactions on Industrial Electronics*, vol. 36, no. 4, pp. 475–479, 1989.

[30] R. P. Aguilera *et al.*, “Selective Harmonic Elimination Model Predictive Control for Multilevel Power Converters,” *IEEE Transactions on Power Electronics*, vol. 32, no. 3, pp. 2416–2426, Mar. 2017, doi: 10.1109/TPEL.2016.2568211.

[31] M. Uddin, S. Mekhilef, M. Rivera, and J. Rodriguez, “Predictive indirect matrix converter fed torque ripple minimization with weighting factor optimization,” 2014, pp. 3574–3581.

[32] J. Rodriguez and P. Cortes, Predictive Control of Power Converters and Electrical Drives. Wiley-IEEE Press, 2012.

[33] CONTROLO’2014 – Proceedings of the 11th Portuguese Conference on Automatic control publié par António Paulo Moreira, Aníbal Matos, Germano Veig

[34] S. Kwak, U. Moon, et J. Park, « Predictive-Control-Based Direct Power Control With an Adaptive Parameter Identification Technique for Improved AFE Performance », *IEEE Trans. Power Electron.*, vol. 29, n° 11, p. 6178□6187, nov. 2014, doi: 10.1109/TPEL.2014.2298041.

[35] X. Zhang, L. Zhang, et Y. Zhang, « Model Predictive Current Control for PMSM Drives With Parameter Robustness Improvement », *IEEE Trans. Power Electron.*, vol. 34, n° 2, p. 1645□1657, févr. 2019, doi: 10.1109/TPEL.2018.2835835.