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Spécialité : **Traction électrique**

Thème :

Amélioration de la commande prédictive à base du modèle (MPC) appliquée aux convertisseurs statiques : Etat de l'art.

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ملخص:

الغرض من هذا الموضوع هو وضع توليف ببليوغرافي لمختلف التقنيات المستخدمةولتخفيض وقت الحساب هذا وتحسين أداء الرقابة التنبؤية المطبق على المحولات الساكنة.

الكلمات الرئيسية: التحكم ، التنبؤات القائمة على النماذج ، المحولات المصفوفية.

Abstact

The purpose of this topic is to make a bibliographical synthesis on the different techniques usedin order to reduce this computation time and improve the predictive control (MPC) performance appliedto the static converters.

Keywords: model-based predictive control (MPC), control , matrix converter .

Resumé

Le but de ce sujet est de faire une synthèse bibliographique sur les différentes techniques employéesafin de réduire ce temps de calcul et améliorer les performances de la commande prédictive (MPC) appliquéesaux convertisseurs statiques.

Mots clés : commande prédictive à base du modèle (MPC), commande ,convertisseur matricielle .

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Dedication

First of all , I would like to thank the person 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 precious mother.

I dedicate this work

To my late father, whom I hope to be proud of me, may God welcomes him into his vast paradise.

To my Grandmother, May Allah prolongs her life and grants her health.

To my brother KARIM, my confident, the person who always takes care of me, may god bless him.

To my sisters CHAYMA and NOOR who are always there for me.

To my late childhood friend Imane , may God welcomes her into his vast paradise

To my best friend Aya who never stopped believing in me and for her precious help as partner.

To My friends Maroua and Sonia

INTISSAR

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State of the art

Improvement of model
predictive control

General introduction:

Power electronics is a mature technology that has been in use for more than four decades. From air-conditioners to rail transport and from mobile phones to motor drives, 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].

Over the years 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 [4, 5, 6,7].

In MPC, an optimization problem is formulated based on an objective function that captures the control objectives over a finite prediction horizon. The control action is determined by minimizing in real-time and at every time-step the chosen objective function, subject to the discrete-time model of the system and constraints. The sequence of control inputs with the minimum associated cost is the optimal solution.

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

II- Overview to matrix converter

Power electronics is a technology that facilitates electrical energy conversion between source and load based on the combined knowledge of energy systems, electronics and control, and this action is made by converters which are electronic circuit based on high power handling semiconductor devices, energy storage elements and magnetic transformer. A well-known example AC-AC frequency converter

Frequency converters convert AC electrical power of one frequency into AC electrical power of different frequency [8]. In addition, this kind of converter also has the capability to control the load voltage amplitude, the displacement angle between source currents and voltages (input power factor) and also, the capability to control bi-directional (or only unidirectional) power flow through the converter [8].

As the popularity of AC motors in the industry continues to grow, AC - AC converters are used in the applications of variable speed drives to control the speed and torque of current motors alternative. AC - AC converters can be divided into two types: Indirect Converters and Direct converters

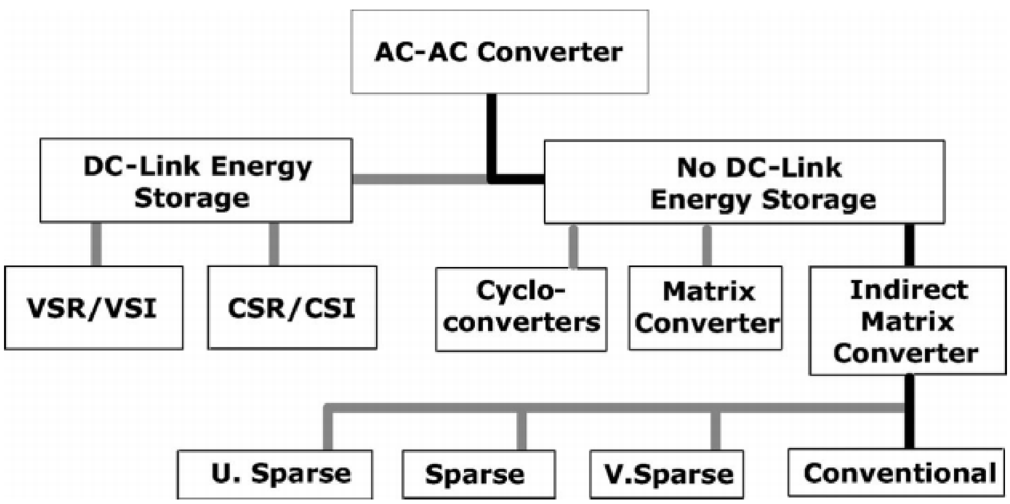


Figure II- 1: Classification of power converters

III.1 Direct matrix converter

Direct Matrix converter, which uses the principle of single stage AC- AC conversion without the need of energy storage elements, it is able to convert AC voltage into another AC voltage [9]. They offer inherent advantages such as bi-directional power flow, nearly sinusoidal input and output waveform Also the input power factor, output current amplitude , frequency are controllable .Finally they have a compact design and they do not need DC-link capacitors for energy storage [10].

Using the fully controlled bi-directional switches, that performs direct energy conversion without any energy storage elements in an intermediate link, to connect directly the inputs to the outputs. The matrix converter is also able to generate an adjustable input power factor regardless of the load [11]

The concept of a direct MC appeared in the literature as early as the 1970. Research started more extensive with the work of Venturing and Alexia in the 1980 [8]

The absence of the DC-link capacitor reduces the volume, enhances the efficiency, increases the lifetime and simplifies the control schemes. It only requires small filters to suppress the ripples generated by the switching actions [12]

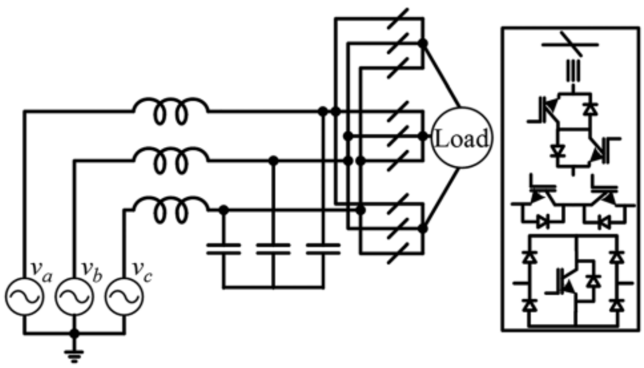


Figure II- 2: Direct matrix converter (DMC)

III.2 Indirect matrix converters

The IMC offers a set of advantages such as simpler commutation [13] , clamp circuit for overvoltage protection [14] , possibility of reducing the rectifier-stage switch count, while providing similar performance as that of direct matrix converter. Multi-modular topologies for IMC have been proposed that they allow for modification of output stage to meet different application requirements. Modern variable frequency drives powered by high switching frequency power converters, such as MC, have made it possible to an accurately and efficiently control AC machines.

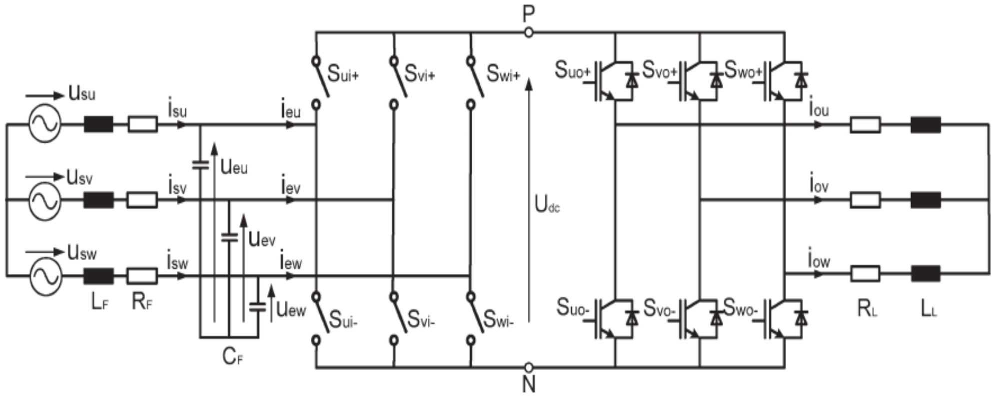


Figure II- 3 :*Indirect Matrix Converter (IMC)*

III.3 Different structures of indirect matrix converters

III.3.1 Conventional indirect matrix converters

The conventional IMC perform AC/DC/AC power conversion in two stages, namely, rectification and inversion stages in addition to a storage element which can be either a capacitor or an inductor [15].The rectifier stage, which is formed by six bidirectional switching, provides a fictitious DC link voltage with a variable average. The other six unidirectional switching forming the inverter stage, are synthesizes three-phase output voltages. [16]

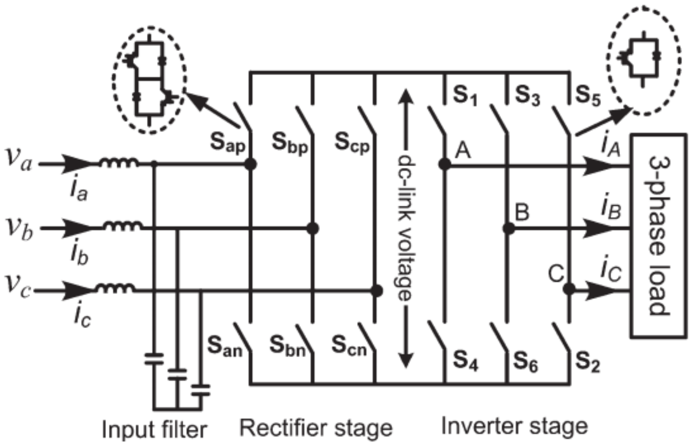


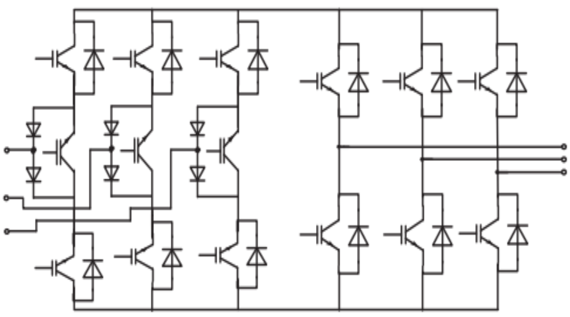
Figure II- 4: Structure of a conventional indirect matrix converter

III.3.1.1 Sparses indirect matrix converters

The IMC topology has a complex control for the number of switches to handle. In order to reduce the number of transistors, one IGBT from each leg of the rectifier is eliminated, compared to the previous configuration to be sparse indirect matrix converters (SMC).

By an implementation of bidirectional IGBT switches connected to a diode bridge, where the number of the controlled components in the rectifier is reduced, a very sparse IMC structure is created .[17]

In ultra-sparse indirect matrix converters configuration, minimum number of switches are employed. There is a single switch by input. The bidirectional power flow cannot be handled due to the structure of the rectifier, which limits its practical application like aerospace. [17]



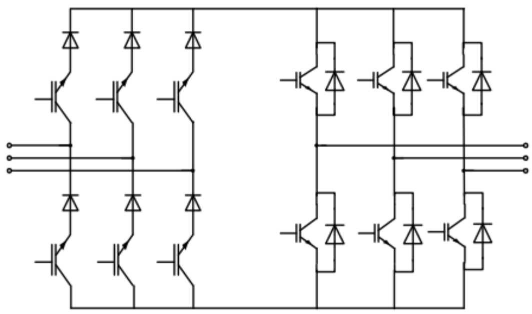


Figure II- 5: Sparse matrix converter (SMC)**Figure II- 6Verysparse matrix converter**

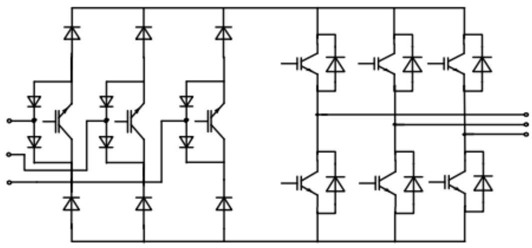


Figure II- 7: Ultra sparse matrix converter (USMC)

III.3.1.2 Multilevel indirect matrix converters

The multilevel MC can synthesize more than two-level output voltage to improve output performance in terms of reduced harmonic content. [18] .The conventional multilevel IMC topology was firstly based on the traditional IMC, but with six-switch inverter no sense in the back replaced by a three-level neutral-point-clamped (NPC) inverter [19] . Then, the new multilevel IMC based on the combination of conventional NPC and cascaded-rectifier [20] in order to improve the voltage transfer ratio

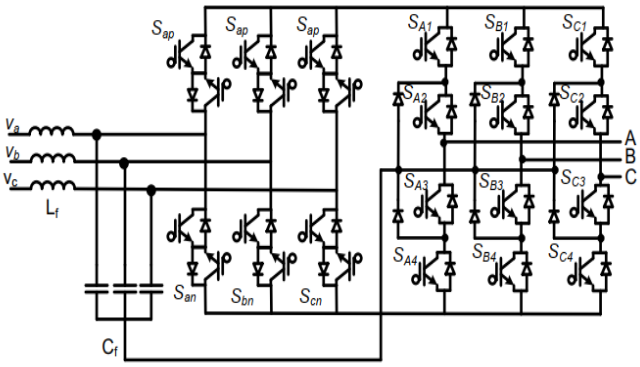


Figure II- 8: Multi level IMC

IV.1 Principal work of model predictive control

In the 1970s an advanced control methodology was developed in the process control industry—starting mainly from the petrochemical industry—known as model predictive control (MPC). Since then, the introduced control strategy has been gaining more widespread popularity. The reasons for this could be posited as being primarily twofold. The advent of faster microprocessors with increased computational capabilities, as well as the advantageous features of this optimal control strategy, enabled its application in many other sectors and industries, including the field of power electronics. Some of the most important features include its design simplicity due to the straightforward implementation procedure, the explicit inclusion of design criteria (constraints), and its ability to handle complex and nonlinear dynamics. Furthermore, in contrast to classical control methods, mainly based on the proportional-integral-derivative (PID) controller, MPC can be easily applied to a wider range of systems such as nonlinear plants, multi-input, multi-output (MIMO) plants, or input- and/or output-constrained plants.

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

IV.2 MPC Strategy

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

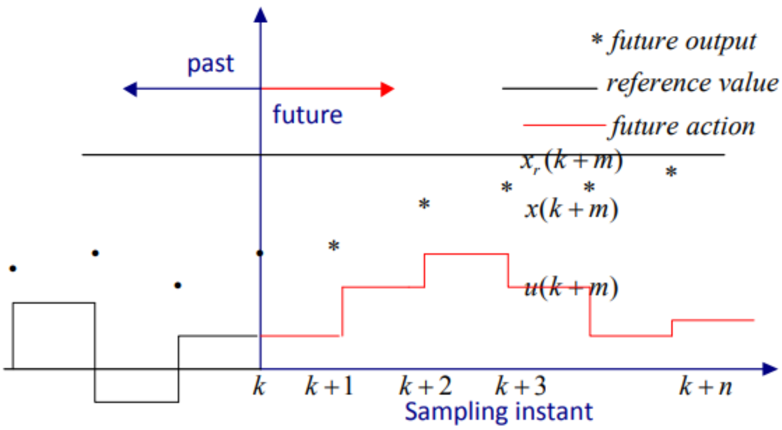


Figure III- 1: Working principle of MPC

MPC defines the control action by minimizing a cost function that describes the desired system behavior. This cost function compares the predicted system output with a reference. The predicted outputs are computed from the system model. In general, for each sampling time, the MPC controller calculates a control action sequence that minimizes the cost function, but only the first element of this sequence is applied to the system. Although MPC controllers solve an open-loop optimal control problem, the MPC algorithm is repeated in a receding horizon fashionat every sampling time, thus, providing a feedback loop and potential robustness with respect to system uncertainties [21].

IV.3 MPC's Elements

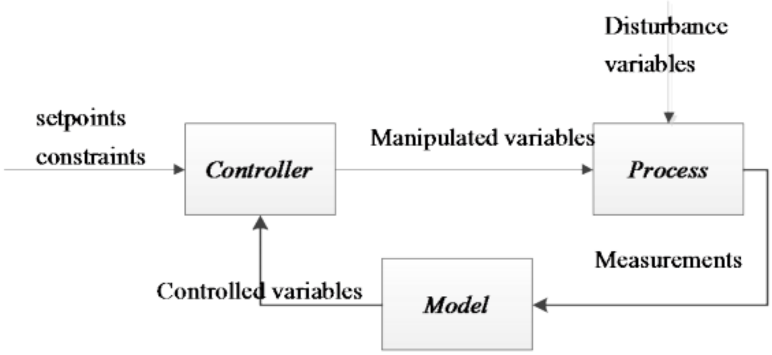


Figure III- 2 : Basic structure of MPC

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

IV.4 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.

IV.5 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]

V.1 Application 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 that the 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 modulator thus 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

V.2 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.

V.3 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.

V.4 Conclusion

Model Predictive Control (MPC) is a very attractive solution for controlling power electronic applications. This paper presents the current state of MPC for power converters and drives including the most recent advances and trends. The operating principle of MPC has been reviewed, and the it can be concluded that the implementation of MPC depends on three key 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.

The paper summarizes different solutions for these matters that have been proposed in the literature, introducing the most important advances in MPC applied to power converters and drives

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