Guest Editorial:
Special Section on Predictive Control in Power Electronics, Electrical Drives and Industrial Applications

The features and potential of predictive control techniques in power electronics applications have been demonstrated and widely studied during the last 15 years. The most remarkable advantages are the intuitive control scheme, great flexibility to cover a variety of degrees of freedom, and the straightforward incorporation of nonlinear variables and constraints. Although this proposal with very attractive characteristics dates back to the 1970s, the experimental validation has only been possible recently, thanks to the development of modern digital controllers due to the relatively high computational burden associated with this method. The great effort of the researchers enabled a large number of publications in journals and dedicated conferences that has positioned this strategy as a viable alternative to the classical controllers. Thus, implementations based on this approach in proposals such as variable-speed drives, current, voltage, and power regulation, renewable energy generation systems, microgrids, energy storage, or electric vehicles (EVs) can be found in the literature. It is expected that the pace of developments with the predictive control keeps the current trend, because of the great opportunities in the research and industrial fields.

The challenges in this area are currently focused on the improvement of classic operation characteristics accomplished such as variable switching frequency of the power devices or steady-state error, tuning of the weighting factors of the cost function, or the reduction of the computational load by simplifying the optimization algorithm. Furthermore, enhancements in the performance such as reduction of the error and ripple of the regulated variables by introducing new observers or applying adaptations in the model, robust schemes, hybrid architectures, and developments with the integration of artificial intelligence tools are also extending the state of the art of this technology. The advancements in these aspects will provide the maturity and improve the competitiveness to the predictive control for a progressive introduction in the industry.

It is a great pleasure for us to present this Special Section dedicated to the predictive control in the IEEE Journal of Emerging and Selected Topics on Power Electronics. This Special Section is proposed to contribute to the development of this technology providing the last advancements with the aim of generating the impact in the academy and the industry. For this reason, the official designation is “Special Section on Predictive Control in Power Electronics, Electrical Drives and Industrial Applications.” Hence, subjects related to the design of electric machines, pulse width modulation (PWM) along with other trends in power electronics, and the industry also take part in this collection of papers. The current interest in the predictive control was demonstrated with a total of 141 manuscripts received. Twenty original works that cover a variety of topics within the scope of this proposal are accepted. They are roughly grouped into six areas: 1) electric drives; 2) grid applications; 3) storage and energy management; 4) power, voltage, and current control; 5) fault tolerance; and 6) resonant techniques.

The first topic is electric drives. This is opening with four developments that employ one of the most popular designs in the research field, the permanent magnet synchronous motor (PMSM). A simplified predictive torque control (PTC) of a PMSM fed by a direct matrix converter is introduced by Siami et al. An inverse model is used to reduce the complexity of the optimization process, whereas voltage errors, instead of the flux/torque, are assessed in the output cost function. A lower complexity PTC is also the target by Wu et al., where a mono-objective cost function (only flux error) was developed to regulate the speed of a five-phase PMSM. A finite set of virtual vectors avoids the use of controllers for the harmonics subspace, and the optimization is done with only two of them, which are preselected by using the classic direct torque control (DTC) theory. A hybrid architecture that combines PTC and DTC is derived by Navardi et al. The errors between the predicted flux and virtual flux (voltage–time variables) define the cost function (one term to regulate the stator flux and a second for the torque). In Wu et al. and Navardi et al., the tuning of the cost function is simple, because the terms have the same nature. Next, a deadbeat scheme based on a robust model of the PMSM that incorporates the magnetic direct- and cross-saturation effects is presented by Kakosimos and Abu-Rub. The accurate identification of the drive’s parameters is performed with a finite-element method.

The modulated model predictive control is the scheme promoted to attain constant switching frequency and is used by Li et al. for the current control of a brushless doubly fed induction machine. The modulation is embedded in the predictive control architecture, and the optimum space voltage vectors with their respective dwell time are obtained in the optimization process. A robust control strategy for doubly fed induction generator was developed by Filho et al.
The predictive model considers the variation of the parameters to achieve an accurate evaluation of the cost function based on voltage errors. Carrying on with robust controllers, the method of Yin et al. presents an immune-optimized disturbance observer for an induction motor. This works, in essence, as a compensator, while the machine parameters are previously optimized to extend the performance of the closed-loop system. A biaxial mechanism powered by two PMSMs is controlled by Shi et al. with a predictive control strategy. The two drives are modeled as a unique system, and the flexibility of the cost function is exploited including several control criteria. An adaptive adjustment of the most influential weighting factor values improves the steady-state response.

The contribution attained by Beigi and Karami, the last in the category of electric drives, employs the finite-element approach to optimize the turn-ON and turn-OFF control angles of a brushless dc motor for adjustable speed applications. This study covers a wide range of speeds, and the maximum torque is achieved with this sequence computed off-line.

The second subject is grid applications, where current and power control strategies are presented. The first proposal of this category, Judewicz et al., reports a generalized predictive control for a grid-connected voltage source inverter through an LCL filter. The full-order filter model is one of the innovations along with the parameters’ sensitivity analysis to identify the allowable variation of the inductance to meet at the same time robustness and quality restrictions. Next, a modulated current controller for a grid-connected three-level T-type power converter is presented by Lee and Lee et al. A finite-set with high-order number of virtual vectors are used, but in the optimization process, only the four nearest to a reference voltage are chosen as candidates. The balance of the dc bus is regulated by injecting a zero-sequence voltage defined with the optimization of an auxiliary cost function for this degree of freedom. Always taking into consideration the current regulation, the robust implementation of Cao et al. models a single-phase grid-connected system aided by a predictor filter to overcome the effects of calculations delays and an adaptive voltage compensator to overwhelm the steady-state disturbances. The last application in this topic is a photovoltaic (PV) generation system tied to the grid with a quasi-Z source inverter (Jain et al.). A predictive current control harvests the maximum power available by the PV. The cost function has a term to limit the commutation of the power switches during the steady state, whereas high switching frequency is allowed adaptively during the transient state to achieve a fast response.

Microgrids and EVs are the two fields of applications reported in the storage and energy management section. First, a grid-connected dc microgrid composed of PV generation, load, and storage (batteries) components is the network under study by Lee and Zhang et al. The predictive model for the generation and demand is based on historical data and stochastic process, whereas the energy storage system is regulated with a predictive control scheme. The goal of the strategy is to minimize the power extracted from the grid. The proposal (Zhu et al.) is a battery thermal management unit for the lithium-ion batteries of an EV. A nonlinear and time-variant thermoelectric model calculates the predictions, while the cost function incorporates constraints such as temperature and energy consumptions for the heating/cooling to regulate the temperature with high efficiency.

The next group for the regulation of voltage/current/power is analyzed as follows. The control of parallel dual-active bridges is dealt by An et al. The current stress is previously optimized and then implemented in a predictive current scheme based on the dual-phase-shift strategy. It was demonstrated that this method enables the balancing of the power injected by the parallel dc–dc power converters in a wide operation range. Finalizing this group of contributions, Zhou et al. introduce a digital-average-voltage and current predictive controller for dc–dc applications. The voltage and current are regulated simultaneously by defining a cost function with these criteria. The technique was assessed in a buck-type power converter operating in the continuous conduction mode, demonstrating fast response without subharmonic oscillations.

The fault-tolerant category contributes to the diagnosis and postfault control in the open-circuit case, Zhang et al. and Huang et al. The first development, Zhang et al., is an online open-circuit fault diagnosis strategy for a direct matrix converter. The faulty is detected with measurements and expert knowledge of the recirculating paths under the presence of a single-phase open. A postfault-modulated predictive current control for five-phase flux-switched permanent magnet motor drive is introduced by Huang et al. The case of study is single open phase, and the finite set of voltage space vectors is reduced by taking off the ones with large projections in the harmonic subspace. The switching state that minimizes the cost function is postprocessed in a duty cycle optimization algorithm to generate a double-edge symmetric PWM implementation.

The last topic of this number is the resonant power converters. One of the applications of this technology is the light-load efficiency. This utilization is reported by Fei et al., where an LLC resonant converter is controlled with an adaptive burst mode simplified optimal trajectory control. This method demonstrates a high efficiency and attractive features such as low voltage ripple, low computational requirement, and fast transient response.

We hope that this Special Section will encourage the electric drive and systems community to keep the interest and effort on predictive control techniques and that it will enable further developments in different applications as well as increased involvement in the industry in the coming years.

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