Journal of Engineering and Applied Sciences 13 (Special Issue 1): 2242-2253, 2018
ISSN: 1816-949X

A Review of Different Control Methods in Power Electronic

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Abstract: This study examines variations in power electronics that incorporate different types of power converters such as rectifier from AC-DC and inverter from DC-AC. Power electronic mechanism consists of power and converter elements. Power elements include electric chokes, switch transformers, fuses, capacitors and resistors which transfer energy from the source to the load. The control environment is proficient to the root of assemblage of control casting collected from the power component of the equipment. The controllers aim to achieve satisfactory performance at steady state error because of its necessary usefulness in connected convertors and ability to boost disturbance refusal by canceling voltage harmonics. This study discusses the changing techniques of controllers used in straight forward and complex analytical methods. Converter control methods are classified as hysteresis, inner, sliding mode, predictive and artificial intelligent control. This study investigates each type of control and brief discusses their features, namely, block diagram and vector.

Key words: Converter control, control method, DPC, DTC, FOC, VOC, artificial intelligent control

INTRODUCTION

Semiconductor devices include switches that convert power and the process of controlling and conditioning electric power (Rashid, 2010; Erickson and Maksimovic, 2007; Blaabjerg *et al*., 2004).The most important issue faced by industries is the reliability of power converters. The wide applications of power electronics span from high-power applications of electric power transmission systems and low power systems such as mobile applications. Electronic devices and control circuits should be extremely strong to increase their life time (Albea-Sanchez, 2010). The efficiency of power electronic systems has been thoroughly examined at present because of the economic and environmental significance of power losses and the increasing cost of energy dissipation. A small improvement in the power efficiency of converters can enhance outlay productivity in the electronic market (Gutfleisch *et al*., 2011; Eirea, 2006).

Power converters such as DC-AC, DC-DC, AC-DC can be classified as light, nuclear and thermal (Erickson and Maksimovic, 2007; Mohan and Undeland, 2007; Bird *et al*., 1992). Power electronic devices consist of two parts.

Power: Power elements element deliver energy from the source to the load. Power elements are compounded to convert circuits suitable to the load. The semiconductor characteristic of the converter should operate in pulse mode (switching) to ensure minimal power losses. Semiconductors could be either controllable (transistors, thyristors) or non-controllable (diodes) (Middlebrook and Cuk, 1981; Bordry, 2004).

Control part: Regulation or control is established from the control block that collected information from the power component. The collected information belongs to the output current/voltage or to voltage/load of the transistor in the converter.

Control devices aim to reach eligible execution in steady state error conditions caused by voltage harmonics. Control methods ranged from simple to complex these controllers are discussed briefly (Rossiter, 2003; Fradkov *et al*., 2014).

MATERIALS AND METHODS

Hysteresis control: Hysteresis is a characteristic of highly nonlinear equipment or parameters that are difficult to model. Given that several outputs can be connected with the same input, system composition may exhibit path dependence. Hysteresis can be described as delay in the response of a material when supplied with actions. Magnets in magnetic hysteresis may demonstrate varied

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magnetization values without a functional magnetic field. Magnetization cannot be established without input history information (Leung and Chung, 2005; Malesani *et al*., 1997; Okumus and Aktas, 2010; Malinowski *et al*., 2003).

Current control: Current control mechanism supported by hysteresis algorithms are used frequently. An example of this mechanism is active filtering motion control or active/reactive power delivery control in distributed generation systems. A quick and robust dynamic response is delivered from the current control of hysteresis. This response requires simple achievement and execution in a typical digital signal principle. A major disadvantage of hysteresis current control is the hanging switching frequency because of fixed hysteresis band (Malesani *et al*., 1997; Bose, 1990; Dalessandro *et al*., 2005).

Hysteric Direct Torque Control (DTC): In the mid 1980's, Takahashi and Noguchi proposed a simple control strategy to enhance the performance of induction motor. This control strategy is popularly known as DTC (Bobrowska-Rafa *et al*., 2009; Zhang and Qu, 2015). This method replaced the traditional method Field-Oriented Control (FOC) method proposed by Erickson and Maksimovic (2007). FOC was extensively used to control the AC quantities of stator flux, currents and voltages using vector control approach. This scheme is complicated because of the presence of frame transformation and current controller and the need for knowledge in machine parameters. The flux and torque in DTC are controlled by choosing the appropriate voltage which is determined by considering the status of digital hysteresis controllers. By contrast, the flux and torque in FOC are controlled by the generated current or the d-q axis component of stator current that refers to the excitation reference frame, this process results in complex mathematical equations (Bobrowska-Rafa *et al*., 2009).

Despite its complicity, DTC has two significant problems, namely, the changing or unstable frequency of switching and enormous torque ripple. These problems are caused by unpredictable torque and flux control behavior under varied conditions of hysteresis operation. Several researchers proposed minor adjustments to address these problems. Space vector modulation method is the most popular method used to overcome this issue. According by Blaabjerg *et al*. (2004), space vector modulation is widely used by researchers to improve motor performance. The major difference between DTC-SVM and DTC hysteresis is the process of generating stator voltage reference. In DTC-SVM, stator voltage reference can be derived through calculation within a specified sampling time (Albea-Sanchez, 2010; Gutfleisch *et al*., 2011). Unlike DTC hysteresis, this process can achieve constant switching. The process of generating stator voltage references involves complex calculations devices. Another improvement is the use of a variable hysteresis band. Torque ripple decreases when the bandwidth of hysteresis band is reduced. Reverse voltage vector can occur whenever the torque changes rapidly under extreme conditions such as at extremely low speed. This mean condition means that the overshoot and undershoot of torque could vary outside the hysteresis bands there by producing extreme torque ripple caused by the inappropriate selection of voltage vector. The dithering method is used to improve switching frequency (Eirea, 2006; Mohan and Undeland, 2007). This method is applied by injecting the high switching frequency of the error component to the flux and torque. However, this approach cannot maintain switching frequency. Several techniques were adopted in DTC drives to overcome this problem and enhance the performance of motor drives (Bird *et al*., 1992; Middlebrook and Cuk, 1981).

DTC: FOC is a promising control technique but this approach is dependent of the accurate parameters of the motor. Rotor time constant is difficult to calculate accurately because it constantly changes with temperature (Ozkop and Okumus, 2008). The equations below are used to establish a strong control system by calculating the flux and torque:

$$\varphi_{ds} = \int (V_{ds} - R_s i_{ds})dt$$

$$\varphi_{qs} = \int (V_{qs} - R_s i_{qs})dt$$

$$\hat{\varphi}_s = \sqrt{\varphi_{ds}^2 + \varphi_{qs}^2} < \operatorname{atan}\left(\frac{\varphi_{qs}}{\varphi_{ds}}\right)$$

$$T_e = 1.5\ p\ (\varphi_{ds} i_{qs} - \varphi_{qs} i_{ds})$$

The flux and torque are controlled by comparing them with the particular values of hysteresis comparators. The output is then utilized as input signals to the switching table. Table 1 shows the suitable switching state of the inverter. Figure 1 shows the simple structural configuration of DTC. This superior structure can enhance torque and flux control through fast dynamic and reliable control facilitated by hysteresis operation. This approach can facilitate appropriate voltage selection and independent control of torque and flux. This approach can achieve instant torque and flux control. Selection voltage

Table 1: Switch table

Flux error position	Torque error position	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6
1	1	V2 (110)	V3 (010)	V4 (011)	V5 (001)	V6 (101)	V1 (100)
	0	V7 (111)	V0 (000)	V7 (111)	V0 (000)	V7 (111)	V0 (000)
	-1	V6 (101)	V1 (100)	V2 (110)	V3 (010)	V4 (011)	V5 (001)
0	1	V3 (010)	V4 (011)	V5 (001)	V6 (101)	V1 (100)	V2 (110)
	0	V0 (000)	V7 (111)	V0 (000)	V7 (111)	V0 (000)	V7 (111)
	-1	V5 (001)	V6 (101)	V1 (100)	V2 (110)	V3 (010)	V4 (011)

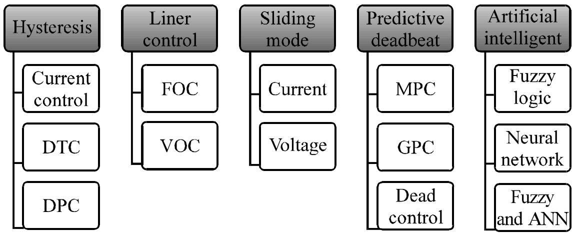

Fig. 1: Presents the common control method

vector or switching state can be obtained in Table 1. The switching table contains three main components, namely, torque and flux status and flux orientation for selecting the appropriate switching state. Switching states are chosen based on the requirement of torque and stator flux to either increase or decrease the stator flux sector. The decision of whether to increase or decrease the stator flux sector is determined based on the three-level and two-level hysteresis of torque and stator flux, respectively. The estimated value of the flux and torque can be derived from the calculation of voltage and current component.

Direct Power Control (DPC): DPC is a of high-featured control design used for PWM rectifiers (Mohan and Undeland, 2007; Zuber *et al*., 2015). DPC does not require comparison between VOC and rotary transformation, PWM block or inner current loop. DPC selects the suitable voltage vector based on a predefined switching table to regulate reactive and active power. Despite its strong robustness, simple structure and quick response, DPC offers power ripples with high steady-state and changing switching frequency. The latest project related to DPC aimed to improve steady-state performance by introducing duty cycle control (Bird *et al*., 1992) or by incorporating SVM (Middlebrook and Cuk, 1981). A few studies have been conducted recently to address DPC control in unbalanced grid voltages. According by Bordry (2004), power compensation block is added to power references to remove the negative-sequence current. Thus, the principle of DPC is preserved. This process requires negative and positive sequence extractions of grid voltages and currents thereby increasing the complexity of computational difficulty of control. Control targets are accomplished per (Rossiter, 2003) by combining power compensations with power references. Sliding mode controller and SVM are used to improve steady-state performance. Positive-sequence grid current and negative-sequence grid voltage should be extracted to calculate power compensations. DPC solution requires the negative and/or positive sequence combination of grid currents and/or voltages. Sequence decomposition is removed to limit complexity. Model Predictive or DPC (MPDPC) is offered as alternative to traditional DPC because of its accuracy and efficiency in vector selection (Fradkov *et al*., 2014; Malesani *et al*., 1997). Selecting the best voltage vector facilitates the modification of steady-state expressions of power ripples, minimizes the cost of power errors and acquires current harmonics. Sampling frequency must be high because only one voltage vector is utilized during the entire control period (Okumus and Aktas, 2010). Steady-state can be remarkably improved by using duty cycle control in MPDPC with considerably reduced variety frequency, this approach is more convenient than by basically mounting the sampling frequency (Malinowski *et al*., 2003). Minimizing power inaccuracy (Malinowski *et al*., 2003) or power ripple root-mean-square minimization (Bose, 1990) was introduced to regulate the period of the chosen voltage vector. Steady-state errors may differ but steady-state performance in duty cycle has no distinct difference. Grid currents are more distorted in unbalanced grid voltages than in single-vector-based MPDPC even if the steady-state execution can be enhanced at below ideal or perfect grid circumstances. Despite the developments in duty cycle developments similar to that by Dalessandro *et al*. (2005), research on MPDPC and PWM rectifiers failed to overcome unstable grid voltage setting.

Fundamental features of standard DPC: The block scheme in Fig. 2 shows the standard DPC configuration. Zero reactive power q_{ref} and active power p_{ref} reference which is delivered from the DC bus voltage controller are compared with the calculated ps and qs values given by Eq. 1 and 2, respectively by means of two-level hysteresis controllers:

$$p_s(t) = v_{sa}.i_{sa}+v_{sb}.v_{sc}.i_{sc}$$

$$q_s(t) = \frac{1}{\sqrt{3}}\left[\left(v_{sb}-v_{sc}\right)i_{sa}+\left(v_{sc}-v_{sa}\right)i_{sb}+\left(v_{sa}-v_{sb}\right)i_{sc}\right]$$

where's (t) and $q_s(t)$ are the instantaneous real and imaginary source power.

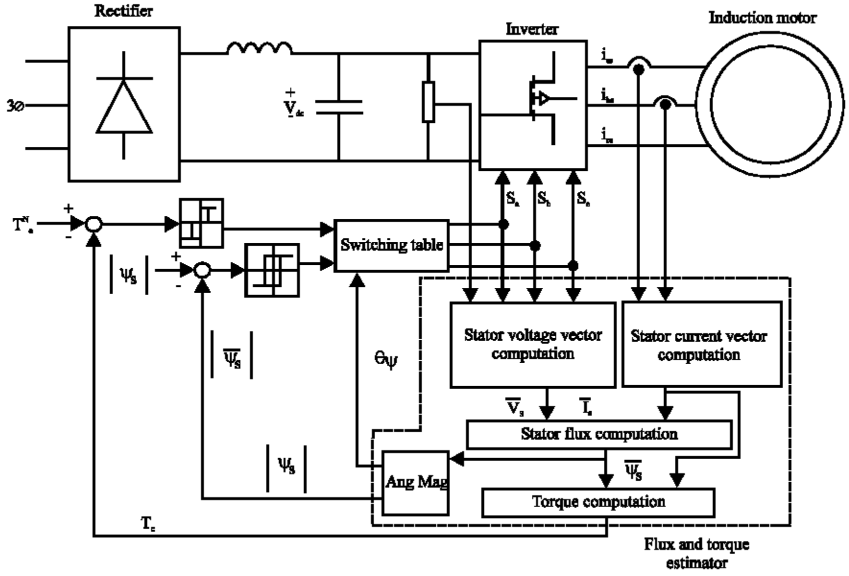

Fig. 2: Simple structure of DTC

Liner control

FOC: FOC can control stator current using vector which is established on forecast, vector transforms phase speed and time subordinate system to d, q coordinates which are coordinate time constant systems (Rashid, 2010; Blaabjerg *et al*., 2004). These forecasts or projections establish the framework of DC machine control. FOC tools required two variables (constants) source as inputs, namely, flux element (line up with d coordinate) and torque element (line up with q coordinate) (Malinowski *et al*., 2003). FOC is established on the forecasting control framework to deal with immediate electrical aggregates. The control framework is operational and accurate (transient and steady state) and unconstrained of the limitation of the mathematics bandwidth model. FOC solved the classical technique by:

- Reaching the constant situation, namely, flux and torque elements of stator current
- Applying direct torque control given that d and q can be found in the following torque equation:

$$m \propto \psi_R I_{Sq}$$

The amplitude of rotor flux (Ψ_R) is maintained at a steady value. The connection among torque elements and torque (I_{Sq}) is linear. The torque is controlled by controlling the torque element of the stator current vector. Motor stator current can be controlled by the control components of FOC by a vector as well as by aligning with rotor flux d, q and by rotating the reference frame. The vector system requires the dynamic model equation for induction motor to provide feedback instantaneous voltages and currents and there by control and compute the variables. Figure 3 shows the relation of stator current and flux space vectors in the d, q rotating reference frame with a stationary reference frame. To facilitate control of induction machines, it must be placed in a perpendicular position to ensure that it can be rotated with rotor flux angular velocity ($\infty_{\lambda r}$) with d d λ axes coincide by means of the direct position of the rotor flux $\bar{\psi}_r$. Hence, torque equation has only a current that is multiplied by only one flux. Moreover, fluxes orthogonal component determination is zero. Meanwhile, the current in torque equation is greater than the projection of stator current vector with $q^{\lambda Y}$ axes which is an active current. The magnetization current of the motor is given by stator current projection to the d^{λ} axes. Thus, the induction motor is controlled by two different loops such as active current (speed or torque) and the reactive current (flux) which are individually excited by a DC motor. The type of the control system is defined by the flux recognition criteria (Malinowski *et al*., 2003).

Figure 4 shows the space pharos diagram of induction machine in short circuit rotor windings. Rotor-resultant-flux orientation is the most used method due to its simple structured control loops and easy calculation. There are two main elements in a space pharos of the stator current that will serve as the control variables. The transformation from the three-phase axes into rotating two-phase "d-q" axes is done by vector rotation techniques. In simpler analysis, the two-phase rotation technique is used to make the case like analyzing separately that are excited by DC motors where there are two independent controlled

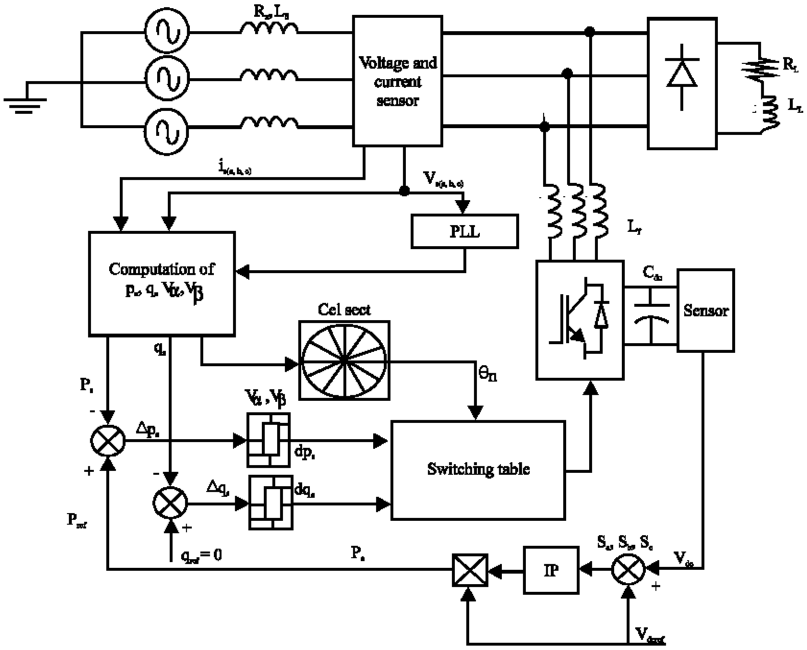

Fig. 3: DPC control block diagram

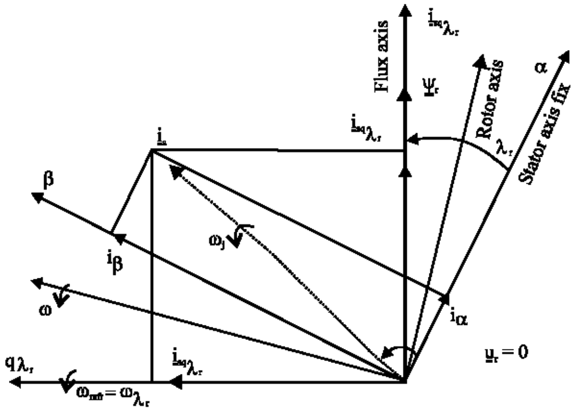

Fig. 4: The vector diagram of FOC principle

currents, the armature current and the field current. The two-phase scheme exactly matches the "a" axis for two-phase system j_α and j_β in stator current at stationary reference frame. The moving "d-q" co-ordinate system is used to control the torque and the field separately and the rotation rate of speeds synchronous to the stationary reference structure.

Estimate j_{-s} on "d-q" output the factors $i_{sd\lambda r}$ and $i_{sd\lambda r}$. Stator current vector required to be disposing to "d-q" in order to control the quantities. λ_γ is the disposing angle. The co-ordinate transformations interconnected to the vector control is described in the literature part. The executed transformations are described here (a, b, c) (,) is the clarke transformation which resulted to a two-co-ordinate time-variant system and (,) (d, q) is the park transformation which resulted to a two co-ordinate time-invariant system.

This is the most important transformation in FOC. Absolutely, this extension modifies a two phase orthogonal scheme in a (d, q) rotary reference structure.

Field oriented control classification: FOC is generally categorized into Indirect FOC and Direct FOC. In the direct field oriented control DFOC the rotor flux vector is calculated either by flux sensor placed in the air slot or by voltage equation. In Indirect Field Oriented Control (IFOC), the rotor flux vector is calculated by field oriented control equations (current model). IFOC is frequently applied in close loop mode due to the operation through speed rang with ease.

Advantages of FOC:

- Improvement of torque response
- Torque control can be implemented at low speed and frequencies
- Accuracy of dynamic speed
- Reduction in motor size, cost and power consumption
- Four-quadrant operation
- Short-term overload capability

Voltage oriented control technique: FOC for induction motors is the origin of voltage-oriented control method for AC-DC converters. FOC provides a fast dynamic

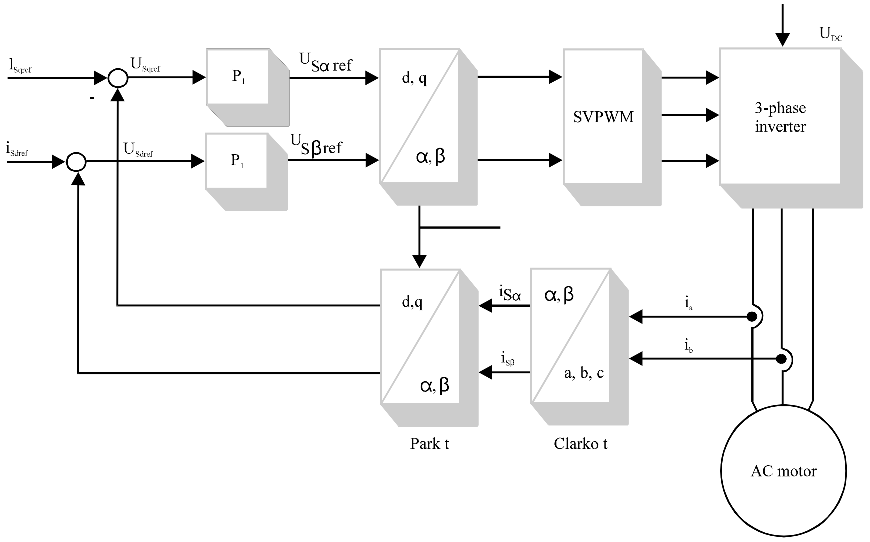

Fig. 5: Fundamental design of FOC for AC-motor

response because of the use of loops of current control. PWM method associated with the control system is applied to ensure that the features of the VOC control system are varied. The effect of interference (disturbances) can be minimized. System solidity is accomplished by applying the hysteresis pulse-width modulation technique. The changing switching frequency contributes to stress in power switching which results in the need for input filter in high-value parameters. Space-vector PWM method can minimize large harmonics in the line current (Blaabjerg *et al*., 2004). Figure 5 shows voltage-oriented control with SV-PWM for AC-DC line-side converters.

AC-side control variables become the DC signals because of vector transformation in the d-q reference frame. Thus, steady-state errors are easily eliminated by the PI controllers. The reference values of the converter input voltages are computed in the current controllers based on the values of the current tracking errors (Eq. 7):

$$u_{convd} = k_p\ (i_{gdref} - i_{gd}) + k_i \int (i_{gdref} - i_{gd}$$

$$u_{convq} = k_p\ (i_{gqref} - i_{gq}) + k_i \int (i_{gqref} - i_{gq}$$

Sliding mode controls: Sliding mode controller is a nonlinear controller type that is adopted to control Variable Structured Systems (VSS). Sliding mode controller can be easily applied with another type of nonlinear controllers (Liu *et al*., 2009; Rain *et al*., 2010; Tan *et al*., 2008; Dal and Teodorescu, 2011). The most important step in sliding mode control is the design of the sliding exterior in state space. The state space has low control to straighten the route of structure state and establish the subjective preliminary state to attain the sliding surface in restricted time. The subjective preliminary state will then reach equilibrium in the original point of the phase plane. The most significant component attributed to the steadiness of SM controllers is hitting condition and stability. Figure 6 shows the representation of sliding mode control principle.

Figure 6 graphical illustration of SM control where S = 0 signifies the sliding surface and x1 = is the voltage error variable and x2 = is voltage error dynamics.

The phase plane is divided by the sliding line into two important regions as shown in Fig. 7. Switching state represents each region. The stable system is functional whereas the route is located in the system stability point. A special characteristic of ideal sliding mode method is infinite switching frequency operation. The function of practical sliding controller at limited switching frequencies corresponds to the quasi-sliding method (Fig. 8).

The advantages of sliding mode controllers are:

- Robust stability under load variation and long lines
- High strength
- Quick and active dynamic reaction
- Uncomplicated accomplishment

The disadvantages of SM controllers are control of converters that experience changes in switching frequency. Integrated Circuit (IC) forms cannot be applied in power electronics. Lack of systematic procedure for design.

Sliding mode current controller: Sliding Mode Control (SMC) is a non-linear procedure that changes the

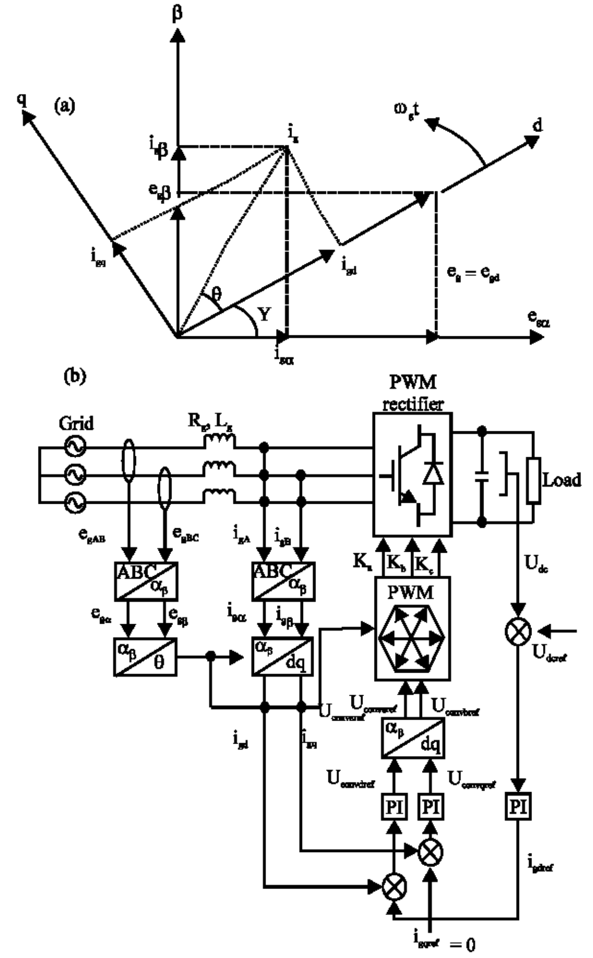

Fig. 6: Voltage-oriented control of PWM rectifiers: a) Vector layout and b) Block diagram

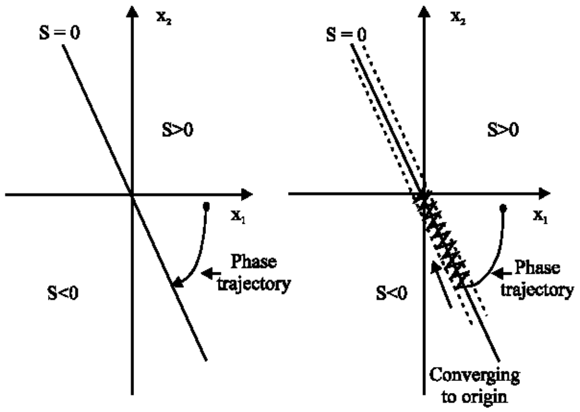

Fig. 7: Phase plot for: a) Ideal SM and b) Actual SM

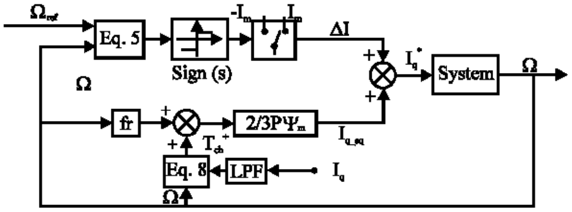

Fig. 8: Scheme of sliding mode controller

structure of non-linear system by introducing interrupted and discontinuous control signal to enable the system to slide in cross-sectional conduct. SMC is a changing control where in the state feedback changes continuously (structure) to a different structure depending on the current status of state space. The control fabrics ensure that trajectories continuously move to the neighboring area. This approach ensures that the trajectory is not located in any control structure and instead slides from the edges of the control structure. System movement from the edges is called “sliding mode” (Rashid, 2010) whereas the geometric position of the edges is called hyper (sliding) surface. SMC design involves two stages:

- Choosing a Suitable (S) switching function for the required dynamic in sliding mode
- Designing multiple sliding controls in system state space

Slide mode voltage control: Boost DC-DC converters are utilized when output voltage is required to be higher than the input voltage. Boost DC-DC converters is harder to control than converters that use the same input output voltage (Rashid, 2010). Control difficulty is attributed to non-minimum phase structure. Various algorithms are utilized to control DC-DC converters and thereby acquire a robust output voltage. Although, DC-DC converters are time-variant and nonlinear, the use of non-linear control methods to control is not adequate. To design a linear system, the small-scale signal is obtained using linearization throughout the accurate operating point. Variation of system parameters cannot be easily accounted for because of the dependence of small signal model parameters on the operating point of the converter (Erickson and Maksimovic, 2007). Change in system parameters is difficult to handle using these methods. Control design remains difficult, especially, for high-order converter topologies (Blaabjerg *et al*., 2004).

A proper control method for DC-DC converters must overcome nonlinearity, wide input voltage and changing load to ensure stable condition during fast reaction. Sliding mode can control this circuit. SM control can overcome and enhance the lack of control technique as basis for small signal model. Sliding mode control enhances the dynamic behavior of the system there by endowing it with characteristics such as robustness against changes in the load, uncertain system parameters and simple implementation (Albea-Sanchez, 2010).

Predictive deadbeat control

Deadbeat control: Deadbeat control is one of the most appealing methods for discrete time control because of its ability to minimize state variable errors to zero in a finite number of sampling steps which usually provides the fastest dynamic response for digital implementation (Mattavelli, 2005). Several methods based on this methodology has been evaluated in the past (Eirea, 2006; Leung and Chung, 2005). The original deadbeat control on output voltage (Eirea, 2006; Mohan and Undeland, 2007) and other similar solutions (Middlebrook and Cuk, 1981) were developed to answer computational delays and obtain fast dynamic response to output voltage at the rated load. However, this approach is limited by the dynamics of other state variables. In discrete time control, deadbeat control is limited by the process of identifying the input signal that must be delivered to system to ensure that the output reachesa steady state in a short time.

When supporting nth-order linear method, the minimum number of steps will be N (depending on the initial condition) if the structure is null (can be contained to state zero by some input). This issue can be addressed by applying feedback to ensure that the poles of the closed-loop transfer function are at the origin of the Z-plane (for more information about transfer functions and the Z-plane, see Z-transform). Thus, the linear case can be easily solved. A closed loop transfer function that contains all poles of the transfer function at the source is sometimes called a deadbeat transfer function. Deadbeat control is difficult to study in nonlinear systems.

Deadbeat controllers are usually used for control because of its robust dynamic characteristic. Deadbeat characteristics are:

- Zero steady-state error
- Minimum rise time
- Minimum settling time
- Overshoot or undershoot percentage at <2%
- Extremely high output control signal

MPC Predictive Control (PC): PC for power electronics was presented in the 1980's (Arnold and Andersson, 2011). A number of featuresensure the suitability of PC in power converters. For example, PCis applicable to different voltage source converters and is easy to understand (Almaktoof *et al.*, 2014). Compared with classical controlling methods, PC requires large calculations. Fast microprocessors facilitate the implementation of PC in Model Predictive Control (MPC) and VSI converters which have better features than traditional PWM methods (Erickson and Maksimovic, 2007; Blaabjerg *et al.*, 2004; Vazquez *et al.*, 2014).

The ingrained discrete quality of power converters is an advantage for MPC power drives and converters. Power converters have limited number of switching states. Thus, MPC optimization can be easily reduced and simplified to project system conduct in the miner of possible switching states. Each projection can be used to estimate cost function (decision or quality function) to ensure that minimum switching state cost is been selected, produced and utilized in the next switching prompt. This Finite State-Model Predictive Control (FS-MPC) is suitable because switching states are finite as well. A variety of drive applications, power converter, three-phase inverter (Albea-Sanchez, 2010; Mohan and Undeland, 2007), flux and torque control of an induction machine (Middlebrook and Cuk, 1981) and matrix converter (Bird *et al.*, 1992) have utilized FS-MPC successfully (Erickson and Maksimovic, 2007). An example of controlled variables that use a single cost function is presented by Bordry (2004) wherein the current is controlled whereas switching frequency is minimized and the DC-link voltage is balanced in an inverter. In the above research, the switching states varied at equidistantly periods of time.

Generalized Predictive Control (GPC): GPC method offers an online resolution to solve the issue, this method is used for long prediction horizons in the absence of high calculation cost (Bird *et al.*, 1992; Rossiter, 2003) GPC is not concerned with semiconductor switching power, GPC functions by applying it to drives and power electronics (El-Kholy, 2005). GPC offers a solution to optimization issue which can be achieved by choosing an unconstrained issue. Moreover, GPC can compute output voltage of the inverter. Voltage is produced using PWM-SVM modulator. Hence, GPC method can take advantage of well-established background of PWM-SVM to optimize power converter systems (Fradkov *et al.*, 2014). GPC is used to calculate control systems. Also, the GPC uses a CARIMA Model to predict system variables with long prediction horizon values (Rossiter, 2003). The block diagram of the GPC strategy is presented in Fig. 9. In this case, it is considered an unconstrained MPC problem.

The GPC design (Eirea, 2006) showed in Fig. 8 contains the plant to be controlled, a reference model to specify the preferred consumption of the plant, a linear model of the plant and the Cost Function Minimization

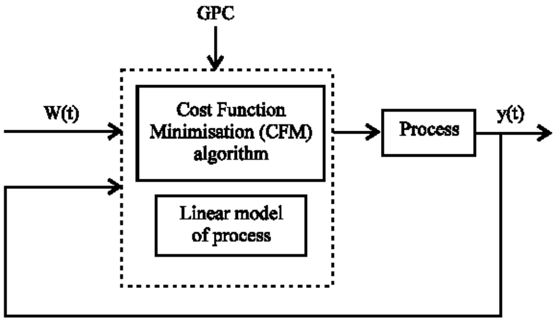

Fig. 9: GPC scheme

(CFM) structure which regulates the desirable input for setting the ideal performance of the plant. The GPC algorithm consists of the CFM block.

The GPC structure begins with the input signal, r(t) which can be obtained from the suggestion model. This model produces tracking reference signal w(t) which is used as an input to the CFM block. The CFM algorithm produces an output which is used as an input to the plant. The CFM algorithm uses this model to calculate control input u(t+1) from the predictions of the response of the plant's model. When the cost function has been minimized, the input is integrated into the plant. This design.

Artificial intelligence

Fuzzy logic controller: Fuzzy logic controllers a nonlinear adaptive control that can be used as alternative for different control applications (Okumus and Aktas, 2010; Malinowski *et al*., 2003; Bose, 1990). The concept of fuzzy logic was proposed by Zhang *et al*. (2014). According to professor Zhang *et al*. (2014) fuzzy logic is not a control methodology but a way of possessing data using partial set membership function instead of crisp (Fig. 9). Fuzzy logic controller system structure has four primary elements, namely, rule base, fusilier, defuzzifier and interface engine. These elements indicate how the fuzzy logic controller can function from the block diagram (Fig. 9). The three main steps are:

- Fuzzification
- Inference
- Defuzzification

The input is a crisp set of data or non-fuzzy data which will be converted using a fusilier with the help of linguistic variables, fuzzy linguistic membership and terms functions.

The numerical value of fuzzy logic should not be fuzzified with membership only because it is the most significant step in fuzzy logic. Membership functions differ from gaussian, trapezoidal and triangular to generalized bell and sigmoid. The backbone of fuzzy logic controller is the rule base. Rule base is defined as:

- Control of the output variable is the purpose of the rule base
- The fuzzy rule is a simple IF-THEN rule with particular condition and conclusion. This rule is represented by the matrix table
- The two variables taken along the axes are error and change in error. The conclusions are provided in the table

Advantages of fuzzy logic controller:

- Low-cost installation on inexpensive sensors and analog to digital converter in low resolution
- The system can be easily be upgraded using new rules for performance improvement or by adding new features
- Fuzzy control can improve the traditional controller systems and provide the system with good performance under the circumstances of load disturbance and parameter changing
- Fuzzy logic controller has higher range than PID for functional state
- The fuzzy controller can function under any disturbance and noise and is cheaper than developing another controller for the same function

Neural Network (NN): Several Artificial Neural Network (ANN) architectures have been proposed. A predominant architecture is the feed forward Neural Network (FNN). The standard neuron structure illustrated in Fig. 1 is adopted which is composed of a summer and logistic function $f(net_{p,i})$ that can be either a sigmoid or a linear function. The equation for the it neuron of the p-the layer structure is:

$$net_{p,i} = \sum_{k=1}^{n} w_{p,ik}\, O_{p-1,k} + \theta_{p,i}$$

$$O_{p,i} = f\,(net_{p,i})$$

Where:

$O_{p,iI}$ = The output

$O_{p-1,}$ = The k-the output at the (p-1) the layer

$w_{p,i,k}$ = The weight from the k-the input of (p-1) the layer to the ithe output of the p-the layer, BPli is the bias. These neurons are organized in layers as shown in Fig. 10

NN and fuzzy control methods: NN control has been applied in current control because of its efficiency. According to Chen and Tang (1999), NN introduce

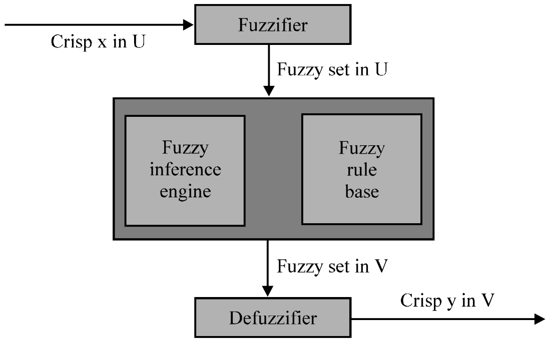

Fig. 10: Overview of fuzzy logic control process

accommodative discrete time grid that connects the system with grid-connected distributed generation inverters. Robust settlement in the non-linear issue is obtained by mixing neural network Grid-Voltage Estimator (NNGVE) with Neural Network Interfacing Parameters Identifier (NNIPI). The learning characteristic of NN algorithm permit an easy adaptable design at various operational conditions and grid disruptions. This condition offers robust sophisticated control compared with other controllers. A new function can be added to the control system such as sensor-less line voltage, synchronization and current control. The total control system deal with computational requirement and complexity thereby resulting in its application in commercial grade digital signal processors (Leung and Chung, 2005). Studies have been conducted to develop and optimize the schemes of current controllers, namely, Fuzzy Logic Controller (FLC), PI-FLC double-mode controller and PI controller, according to Chao and Dagui these approaches can minimize overshoot and track error improvement (Leung and Chung, 2005; Zhang *et al*., 2014).

CONCLUSION

The non-linear condition of power converters and power semiconductors is hysteresis control. Current control can be used to control simple systems but they can also be used for complex systems such as Direct Torque DTC and Direct Power a Control DPC (Middlebrook and Cuk, 1981; Bordry, 2004). Control systems are analog electronics used to execute control systems in digital stand that require high sampling frequency. Changes in switching frequency caused by the width and non-linearity of hysteresis are a problem that can lead to resonance and create spectral content in several applications. Bulky and expensive filters are needed to overcome this issue. Several adjustments for switching frequency control have been suggested. Proportional-Integral (PI) controllers is one of the most familiar option with adjustments in liner controller to facilitate use in power converters. FOC is a robust control technique established on linear controllers. Grid-connected converters and Voltage-Oriented Control (VOC) for current can use the same technique. Supplementary coordinate transformations are needed for linear control systems. Unstable performance in the dynamic domain is caused by the use of a linear control system instead of a non-linear system. Digitalization needs a sampled data that can control systems such as continuous-time linear controller which considers all adjustments steps. Additional design stages are needed to achieve robust control system and obtain a significantly hard power control system such as multilevel converters and matrix. Power converters systems are dependent on the technical needs of some system, restriction [maximum current, Total Harmonic Distortion (THD)] and maximum switching frequency which are not included in design of linear controller. The classical control theorem has been modified several times to facilitate its use in digital converters. New control systems have been introduced as a result of innovation in robust microprocessors, sliding mode control, neural networks, predictive control and fuzzy logic control which are all examples of powerful control systems. The important findings of this research are listed as. The performance of power converter is strictly dependent on the ability of its designed controller. Therefore, it is crucial to include all possible power system conditions in the design process especially for the design of grid-connected converters.

Each control method has its own advantages and disadvantages to suit different types of applications. There are actually no versatile methods in terms of cost and performance and the best method is commonly referred to the best trade-off obtained between cost and performance.

PWM method is the most commonly applied method in controlling power converters. Additional refinement such as incorporating advantages of FLC is one of the best ways to enhance ability of the designed control system.

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