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Grid-Tied Inverters Control based on D-Q Control Algorithm and Review of different control methods and controllers

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Abstract— A efficient grid-tied inverters must meet severe controller performance in both transient and steady state circumstances. Grid-tied inverters have been subjected to a plethora of control methods. There are, however, just a few books that examine the review on these grids connected inverter control systems and their categorization, especially in light of current breakthroughs in this field. An investigation of grid-tied inverter control methods is presented in this study. These grids connected inverter control systems are classed and compared as reference frame, modulation mechanism, implementation platform, control strategy, output filter of inverter, and controller. The pros and cons of these characteristics are discussed and contrasted. Then, the most essential properties of these parameters were provided in a table to indicate which parameters may be employed in different grid-tied inverter control systems. Simulation of grid connected converter with dq control method is discussed to control the real power and reactive power in system using MATLAB Simulink.

Keywords—Grid connection, Synchronous reference frame, Controllers, Feed**back loop,** ***Reactive power control.***

I. INTRODUCTION

As the world's population grows, so do the challenges associated with energy distribution, including grid instability, outages, and so on [1]. Distributed energy generation systems (DEGS) provide grids with more adaptability, balance, and stability in response to these issues. In addition, it may enhance network management and minimize carbon emissions [2]. DEGS include wind turbine systems, photovoltaic systems, and energy storage systems such as battery banks, fuel cells, and active filters.

It is required to change the system's DC output voltage to AC before it can be discharged to the grid or utilized to power diverse loads. Grid-connected DEGS need inverters that change the DC current and voltage to AC and distribute them to the grid, therefore inverters are critical. Before it is sent out, the provided energy must be checked for certain qualities and criteria. A proper controller must be used for inverters that change the sort of energy and power they produce. There is a direct connection between DEGS's inverter and the grid's control system. The DEGS output should be as sinusoidal as feasible since the waveform of grid are AC and sinusoidal.

If DEGS is connected to the grid without an appropriate controller, it may cause a wide range of issues, including grid instability and disruption. Consequently, the grid distortions should be able to be eliminated by these solutions. This requires a high-speed controller and a compatibility algorithm.

Additionally, the controller's design is fundamental and significant. The controller's ineffective design is to blame for the grid's instability and failure. Grid distortion can only be countered by an appropriate controller [1].

The overall structure of distributed systems is shown in Fig. 1. It's possible that the electricity generated by the generating system may be distributed to either a utility network or a local load [1].

It is possible to split the control of a distributed system into the following two key categories.

1. Controller in Source side: A controller on the input side aims to extract the highest amount of power possible from a given source of energy. This controller must also safeguard the source side converter.
2. Controller in grid-side and it is capable of the following functions:
    a. grid synchronization.
    b. management of real power provided to grid.
    c. reactive power control transferred between grid and DEGS.
    d. DC-link voltage control.
    e. assurance of good quality power injected to grid., RES utilization is

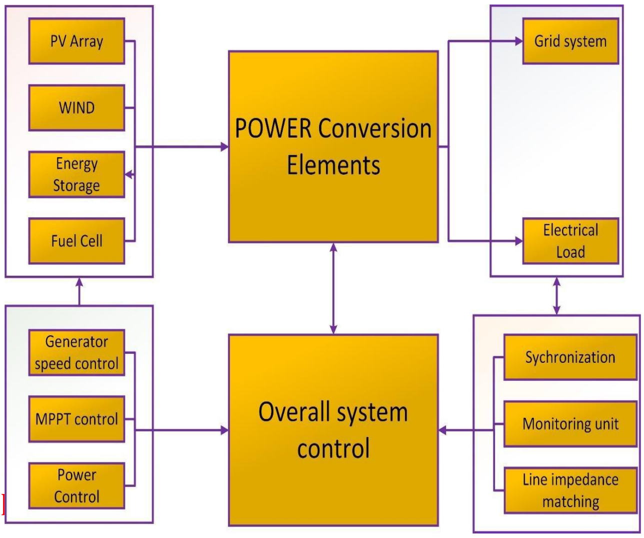


Figure 1. Control structure of the distributed energy generation system

All the properties described above should be present in a grid-side converter. Essential services, such as active filtering, voltage harmonic correction, local frequency, and voltage control, may also be requested by the grid operator [1].

In this study, several grid-connected inverter control methods are examined, and solutions for grid-tied inverter control are reviewed. These control systems are categorized and contrasted as a output filter of the inverter, implementation platform, modulation mechanism, reference frame, control strategy, and controller. Comparison of the pros and cons of various characteristics is made clear. This information is given in a table to indicate which parameters may be utilized in different control systems in grid-tied inverters.

Comparing several distributed generating systems in order to discover the differences, benefits, and drawbacks of each system in order to choose the best control system is what motivates us to write this evaluation. As a result, in Sections 2 and 3, we'll look at how different control systems classify and compare their techniques and parameters. There will be a table in section 4 comparing the various control mechanisms described in reliable scientific journals to the overall table in section 3. Simulation results are presented in section5. Section 6 concludes with a statement.

II. REVIEW ON VARIOUS CONTROL METHOD FOR GRID CONNECTED INVERTER

There are a wide range of variables that may be used to evaluate and compare various control systems.

Various parameters, such as controller, implementation, modulation mechanism, output filter, reference frame, and control strategy are discussed below. In the next section, the controllers will be categorized and described in detail.

2.1 Platform of controller

There are benefits and drawbacks to each of the control systems that may be implemented on either an analogue or digital platform:

2.1.1 Analog controller

By Using Laplace transformation or time-continuous analysis, it is obvious that analogue signals serve as the system's input and output. This platform's merits include its resistance to failure or crash, its great dynamic range, its ability to analyze data continuously, and the availability of diagnostic instruments.

Other flaws include the inability to design comparison logic and intelligent control systems, as well as the inability to do MIMO.

2.1.2 Digital controller

Z-transformation or time discrete analyses are often used to examine and develop the digital signals used by the control system for the platform's digital implementation. Flexibility and rapid creation, as well as ease of comparison logic and intelligent control systems are all advantages that digital platforms have over their analogue counterparts. Additionally, this platform has a poor processing speed, a limited dynamic range, and unintuitive software interfaces.

The following are three types of digital implementation technologies often seen in industrial control systems:

1. Based on a DSP controller [3–5]
2. Based on a FPGA controller [6-8]
3. Based on a microcontroller [9-11]

In the most reliable scientific literature, DSP-based implementation is the most often cited. These articles often employ fixed-point arithmetic to handle data, although more capable

2.2 control system based on theory of reference frame

In grid-connected systems that are well-suited with the distributed system, control systems may be realized in single phase and three-phase distributed systems. single phase and three-phase distributed systems may be transformed into other systems in order to offer a specific capacity for control systems as well as to ease the design process.

2.2.1 Synchronous reference frame

In three-phase systems, this framework is used exactly as in three-phase systems, with no modifications. Current per phase in an ABC frame requires its own controller, but the dela or star connection of three-phase distributed systems must be taken into consideration when designing control systems. This system makes use of non-linear controllers because of the rapid dynamic response they provide.

2.2.2 direct & quadrature reference frame

An abc frame may be transformed into a dq frame using the Park transformation method. These waveforms are shifted into a reference frame that moves in tandem with the grid voltage when this transformation is applied. Control variables are converted into DC variables in this way, allowing them to be filtered and manipulated more simply. The rotating reference frame is shown in Fig. 2

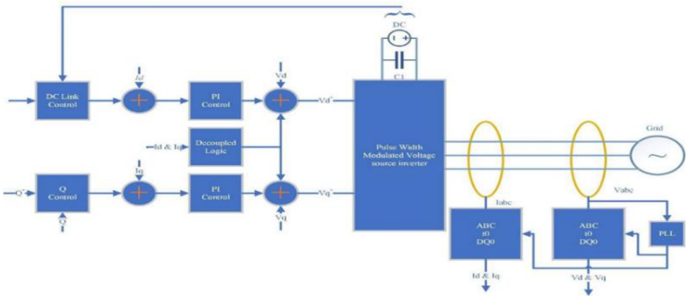


Figure 2. Grid connected Inverter with synchronous rotating reference frame

2.2.3 Alpha -beta reference frame

Typically, this frame is employed in three-phase systems, although it may also be used artificially in one-phase systems. An abc or single-phase frame may be transformed into a - frame using the Clark transformation. There is a reference frame known as a stationary reference frame that is created when the grid current is altered. Sinusoidal values are created as a result of this kind of management. A schematic diagram is shown in Fig. 3 depicting the overall construction of the stationary reference frame.

Figure 3. Grid connected Inverter with Stationary reference frame

2.3 Inverter Filter

Using an output filter, semiconductor switching generates less current harmonics. Filter inductors (L) and combinations with capacitors (LC, LCL) may be used to connect to the output of an inverter. [13]

2.3.1 Inductor Filter

For converters with high switching frequencies, the attenuation provided by the L-filter makes it an ideal first-order filter. Inductance, on the other hand, significantly reduces the converter- filter system's dynamic range.

2.3.2 Inductor -Capacitor Filter

In terms of damping behavior, the LC-filter is superior than the L-filter. This basic topology is straightforward to create and frequently works without difficulties without any troubles at all. It is a compromise between the inductance and the capacity that went into making this filter. Voltage quality is improved by having a large capacity. In contrast, a greater inductance value is required to achieve the desired cut-off frequency. Depending on the impedance of the supply grid, this filter's resonance frequency changes.

2.3.3 Inductor-Capacitor-Inductor Filter

The inverter may operate at a lower switching frequency when the LCL-filter is present. Improved grid-filter decoupling is another benefit of this design. This filter has strong current ripple attenuation despite its tiny inductance values. However, it has the potential to cause the system to become unstable and resonant. As a result, the LCL filter must be properly tailored to the inverter in question.

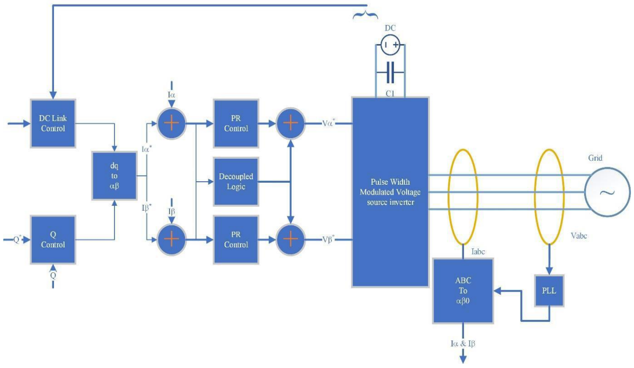
2.4. Method of Control

It is important to have a control system in place to guarantee that stored or injected electricity maintains its high quality. Equivalently, in order to compensate for grid harmonics and the network phase mismatch between voltage and current, capacitors and inductors must be used as loads. The output current of the inverter, the grid current, the load current, or any other node current may be regulated in this manner. As a result of these capabilities, the inverter's structure and its control system should be able to take use of the aforementioned capabilities. A phase- locked loop should be used to integrate the grid voltage phase into the control system. As a result, the fundamental reference current and the grid are synchronized using a PLL. Following is a breakdown of the parameters in the control strategy:

2.4.1 Number of loops in feedback

Single-loop and multi-loop control systems are most often implemented as closed-loop systems, described as follows [14],

When just one parameter is regulated in a single-loop system, the simplistic and low-cost design results in poor performance. In order to optimize the performance of these systems, additional factors outside the primary feedback loop are used. Two feedback loops are employed in this control-based strategy. The structure of these controllers might include a variety of loops, as their name implies. Fig. 6 depicts a basic example with a single inner and outer loop. The dynamic performance of a system is enhanced when the inner loops have a broader bandwidth than the outer loops. As a result of the many sensors used, this form of control is more costly than others.



2.4.2 Parameters Under control

As previously stated, the control system is in charge of carrying out its functions in systems linked to the grid. The grid-connected inverter's control system performs one of the most significant functions of controlling the parameters of voltage, current, and power that may regulate one or more of these parameters based on the required demand from a control system.

2.4.2.1 Control of Voltage

Voltage harmonics are removed, and a suitable amplitude and waveform are injected using this process, which keeps the voltage under control. Photovoltaic and wind turbine systems use this technology extensively on the inverter's input side.

2.4.2.2 Control of current

The current may be regulated in this manner. Additionally, the present harmonics are omitted using this technique. An active filter and energy storage technologies are used on the grid side of things in this manner.

2.4.2.3 Control of power

As a result, active and reactive power may be precisely managed and utilized to provide and store the desired amount of energy to and from the power grid. In addition, the use of DPGS and energy storage devices is a factor.

2.5 Methods on Modulation

Harmonic reduction is a major challenge in the development of power electronic converters. Harmonic reduction in high power converters may be achieved in part via the use of PWM control methods.

PWM methods are used to create a sinusoidal output wave with a predetermined frequency and amplitude.

It's possible to divide the process of creating PWM into two distinct categories: triangle comparison-based (TCPWM) and spatial vector-based (SVR) (SVPWM). An output with a high fundamental component and a low harmonic component is the ultimate objective of any modulation method. As a PWM technique, VLUT is presented in [6].

When a reference modulating signal is compared to a common triangular carrier in TCPWM techniques, PWM pulses may be created. Compared to the modulating signal, the carrier signal has a much higher frequency. The basic component of the grid is controlled by the modulating signal's frequency and magnitude change. PWM and SPWM are two options that come to mind.

A rotating reference vector is used in SVPWM algorithms to supply the reference. Grid-side fundamental component frequency and magnitude are regulated by reference vector frequency and magnitude in this scenario. SVM was first designed for three-phase inverters as a vector approach to PWM. Sinusoidal waves may be generated using more sophisticated techniques that result in a reduced total harmonic distortion (THD).

Introducing the voltage look-up table approach, a brand-new PWM technology introduced in [6]. Voltage reference for converters may be obtained using this approach based on current reference. As a result of its adaptability and simplicity as well as the load situation, this technology has a significant benefit. In addition, the switching frequency in the VLUT approach is much lower than in the other methods.

III. REVIEW BASED ON CONTROLLERS

In the absence of an appropriate controller, connecting a distributed system to the grid may cause a variety of issues, including grid instability and disruption. The controllers are categorized into six groups based on their intended use. A few of these controls may be found in other classes [16].

Linear controllers are part of a group that has linear system characteristics. In order to study and construct these types of controllers, we use the usual feedback control theory.

For example, linear systems and control theory rely on the use of linear controllers such as those described above, which are based on the concept of proportional and integral-derivative controllers. traditional controller is used in [3–6,17–28].

There are a lot of similarities between PR and PI controllers. When it comes to integration, there is a big difference. When using a PR controller, only frequencies that are very near to the resonant frequency are integrated by the integrator. Because of this, stationary errors or phase shifts are not included [29-41].

Combining a linear-quadratic regulator with a Kalman filter is the LQG controller (LQR). These two may be calculated and developed individually thanks to the separation concept.

Both linearly time-varying and linearly time-invariant systems may be controlled using LQG. Linear feedback controllers for nonlinear uncertain systems may be designed by applying LQG control to LTV systems [42]. In [43,44], the control system employs this strategy.

When compared to simple linear controllers, non-linear controllers are a lot more difficult to install and design because of their complex behavior.

It is possible to regulate the output voltage of a PWM inverter using Sliding Mode Control (SMC). The technique's ability to withstand changes in load and parameters is one of its key features. In the ideal instance, invariant steady-state response is possible. On the other hand, finding a surface suitable for gliding is a difficult task. SMC's performance will suffer if the sample rate is too low. When tracking a changeable reference, the SMC approach suffers from the chattering issue. As a result, total system efficiency will be reduced [14]. This controller may be found in [45–50].

Using the feedback linearization method, it is simple to develop nonlinear controllers since it converts a nonlinear system into a partially or completely linear one (PFL Controller). This may be done by eliminating the system's nonlinearities. Consequently, linear controller design approaches may be used to these systems. It is termed precise feedback linearization when the nonlinear system is turned into a completely linear system, and it is called partial feedback linearization when the nonlinear system is transformed into a partly linear system [51]. [51,52]. The PFL controller is utilized in [51,52].

Nonlinear controllers include hysteresis controllers. In order to use a hysteresis controller, a controller adaptive band with a fixed switching frequency must be created. The controller's output is the status of the switches, therefore keeping an eye on the isolated neutral is crucial [1]. [53–58] make use of this particular controller.

Control theory based on the idea that controllers should be designed to deal with uncertainty is known as "robust control." These approaches are aimed at ensuring reliable performance and/or stability even in the face of large modelling mistakes. The robust control relies on well-defined criteria, descriptions, and boundaries. This controller can provide strong stability and performance of closed loop systems even in multivariable systems [59].

H-infinity approaches may be used to address control problems by treating them as optimization problems. In multivariable systems, H-infinity approaches are useful. In spite of

this, it requires a high level of computing complexity and a solid model of the system to be managed. It's also common that nonlinear restrictions get unaddressed [60]. [61–64] make use of this controller.

The impact of both structured and unstructured uncertainty on the system's performance may be examined using the Mu-synthesis technique. The controller is built using the concept of a structured single value in this way. The method's earlier energy and power applications may be found in [63] and [65].

Systems may be automatically controlled using adaptive control techniques, which can automatically alter their actions in response to changes in their operating circumstances. Accurate system parameters are not necessary for high-performance systems. Even still, this control technique has a significant computational complexity [14]. Adaptive control is used in [7,9,66–72].

Control parameters are predicted using a system model by predictive controllers. Based on a predetermined optimization criterion, the controller utilizes this information to gain the optimum actuation. Because of its quick dynamic response time, nonlinearities, and limitations, this controller may be used in a variety of systems, including those with many variables, and it is also simple to design. Predictive controllers need far more calculations than conventional controllers. [73–77] make advantage of this strategy.

The differential equations that govern the dynamic behavior of the controlled system are generated and discretized in the deadbeat control theory. Using these equations, the control signal for state variables is computed at the start of each sample period in order to attain the reference values at the end of the sampling period. There are other instances of this controller in the literature [8,10,78–83].

An MPC flexible criteria specifies a cost function that should be reduced in order to pick the best course of action for a given situation. A model of the system is employed in this method to anticipate the behavior of the variables up to a given time. Control system nonlinearities and system restrictions are readily included into MPC during the design stage [14]. There is a controller in the control system in [11,84–94].

By mimicking the brain's capacity for intelligence, intelligent control may achieve automation. The control challenge may be solved by borrowing ideas from the way biological systems deal with issues [95].

The fundamental concept of repetitive controllers (RC) is derived from the internal model principle. Closed loop tracking and excellent rejection may be obtained if the model of any disturbance or reference is introduced. [96–104] makes advantage of repetitive controllers. During a period, the error signal should be saved in order to establish whether or not the mistake has been eliminated or reduced in subsequent periods. Nonlinear loads may be controlled with a repeating device. The dynamic response of this controller, notwithstanding its suitable performance in the face of periodic nonlinear loads, is undesirable. A parallel or cascade structure may be used to combine the repetitive controller with highly dynamic response controllers in order to tackle this issue.

Virtually every part of the human brain is replicated in a neural network (NN). An optional function mapping may be estimated, and a greater fault tolerance can be achieved. When utilized in a system control, NN may be trained on- or off-line [14]. [105,106] make use of this controller.

Using fuzzy control, a clever human's understanding of a system may be defined and put into action to govern the system. The following parts are found in this controller [95]:

a. It's a set of rules on how to regulate that make up the rule-base.

b. It is necessary to "fuzzify" the numerical inputs before they can be utilized by the inference method.

c. Using information gathered via fuzzification, the inference mechanism determines which rules should be applied to the present situation; it also relies on what the plant input is required to generate judgments.

d. Using defuzzification, the inference mechanism produces a numerical output for the plant based on its findings. The fuzzy controller is used in [107–111].

Complex tasks may be carried out by autonomous systems. Engineers aim to automate human knowledge and techniques directly in order to achieve high degrees of automation in the process of increasing autonomy. In [112], this controller is employed

the open-loop grid synchronization algorithms. However, the absence of PLL restricts the possibilities of an open-loop method. When dealing with steady state defects, open-loop techniques lose their appeal when real-time frequency monitoring is not available. Grid synchronization employs PLL the most frequently because to its simplicity, dependability, and efficiency. On the basis of their benefits and disadvantages, as well as their potential for future improvement, we want to evaluate the performance of several single-phase and three-phase PLL synchronization systems [32]-[37].

IV. ASSESSMENT ON CONTROLLRS USED IN THE GRID CONNECTED INVERTER SYSTEM

There are several control systems to choose from, and their features are briefly discussed in the preceding paragraphs. In many articles, the listed approaches are combined in various ways. To accomplish the duties outlined in section one, the control systems in each of these applications are designed with this as their primary objective. Control systems that have been employed in legitimate scientific papers will be examined here. Table 1 summarizes the most critical features of each group

Ref.	Application	Filter	Control Parameter	Modulationn	Reference Frame	Feedback	Controller	Implementationn
[3]	DG	LCL	Power, Voltage,	PWM	abc-	Single loop	Classic	Analog,Digital

[4]	DG	LC	Current, Voltage	SVM	abc-dq	Dual loop	Classic	Analog,Digital
[5]	DG	LC	Current, Voltage	SPWM	abc-	Dual loop	Classic	Analog,Digital
[6]	DG	L	Voltage	VLUT	abc-dq	Single loop	Classic	Analog,Digital
[7]	General	LCL	Current, Voltage	SPWM	abc-	Dual loop	Adaptive	Analog,Digital
[8]	General	L	Current	PWM	abc-	Single loop	DB	Digital
[9]	APF	LC	Current	SVM	abc-dq	Dual loop	Adaptive, Repetitive	Digital
[10]	General	LCL	Current	PWM	abc-dq	Dual loop	DB	Digital
[11]	DG	LCL	Current	SVM	abc-	Dual loop	Adaptive, MPC	Digital
[17]	DG	L	Current, Power	PWM	abc-dq	Dual loop	Classic	Analog
[18]	APF	LC	Current	PWM	abc-	Dual loop	Classic	Analog
[19]	APF	L	Current	PWM	abc-	Dual loop	Classic	Analog
[27]	DG	L	Current	PWM	abc-	Single loop	Classic	Analog
[28]	PV	LC	Power, Voltage,	PWM	abc-dq	Dual loop	Classic	Analog
[30]	General	LCL	Current	PWM	abc-	Dual loop	Classic, PR	Analog,Digital
[31]	DG	L	Current, Power	SVPWM	abc-	Dual loop	Classic, PR	Analog
[32]	DG	LCL	Current, Voltage	SVM	abc-	Single-loop	PR	Analog
[33]	General	LCL	Current	PWM	abc-dq	Single-loop	Classic, PR	Analog
[34]	PV	LCL	Current	PWM	abc-	Single-loop	PR	Analog
[35]	PV	LCL	Current	SVM	abc-	Single-loop	PR	Analog
[36]	General	LCL	Current	PWM	abc-	Dual loop	PR	Analog
[37]	General	LCL	Current	SPWM	abc-	Dual loop	Classic, PR	Analog
[43]	General	LCL	Current	PWM	abc-dq	Single-loop	LQG	Digital
[44]	PV	L	Current	SVPWM	abc-	Single-loop	PR, LQG	Digital
[45]	UPS	LC	Voltage	PWM	abc-	Dual loop	SMC, Fuzzy	Analog
[50]	PV	L	Current	PWM	abc-dq	Single-loop	SMC	Analog
[52]	PV	LCL	Power, Voltage,	PWM	abc-dq	Single-loop	PFL	Analog
[53]	General	LC	Current, Voltage	PWM	abc-	Dual loop	Classic, Hysteresis	Analog
[54]	General	L	Current	PWM	abc-	Dual loop	Hysteresis	Analog
[58]	General	LCL	Current	PWM	abc-	Single-loop	Hysteresis, MPC	Digital
[61]	General	LC	Current	PWM	abc-dq	Single-loop	H∞, Repetitive	Analog

[62]	General	LC	Current	PWM	abc-	Dual loop	H∞	Analog
[66]	DG	LC	Power	PWM	abc-dq	Dual loop	Adaptive	Analog
[67]	DG	LC	Voltage	SVPWM	abc-dq	Single-loop	Adaptive	Analog
[68]	DG	LC	Voltage	SVPWM	abc-dq	Single-	Adaptive	Analog
[71]	General	L	Current	SPWM	abc-	Single-loop	Adaptive, Repetitive	Digital
[72]	General	L	Current	PWM	abc-	Dual loop	Adaptive	Digital
[73]	UPS	LC	Voltage	SVM	abc-dq	Single-loop	Predictive	Digital
[76]	PV, APF	L	Power	PWM	abc-	Dual loop	Fuzzy, Predictive	Digital
[77]	PV, APF	L	Power	PWM	abc-	Dual loop	SMC, Predictive	Digital
[78]	General	L	Current	SVM	abc-dq	Single-loop	DB	Digital
[79]	General	L	Current	PWM	abc-dq	Single-loop	Adaptive,DB	Digital
[80]	UPS	LC	Current, Voltage	PWM	abc-	Dual loop	DB	Digital
[81]	DG	L	Current	SVPWM	abc-dq	Single-loop	DB	Digital
[83]	UPS	LC	Voltage	PWM	abc-	Single-loop	DB, Repetitive	Digital
[84]	DG	LC	Power	PWM	abc	Single-loop	MPC	Analog
[85]	DG	LCL, LC	Power, Voltage,	PWM	abc	Single-loop	MPC	Analog
[86]	General	LCL	Voltage, Current	PWM	abc	Single-loop	MPC	Digital
[87]	General	L	Current	PWM	abc-	Single-loop	MPC	Digital
[91]	General	L	Current	SVPWM	abc-dq	Single-loop	MPC	Digital
[94]	PV	L	Current	SVM	abc-dq	Single-loop	MPC	Digital
[96]	DG	LC	Current, Power	PWM	abc-	Dual loop	Classic, Repetitive	Analog
[97]	PV	L	Current	SVM	abc-dq	Single-loop	Classic, Repetitive	Digital
[101]	General	LC	Voltage	PWM	abc-	Single-loop	Repetitive	Digital
[102]	General	L	Current, Voltage	PWM	abc	Single-loop	Classic, Repetitive	Digital
[103]	UPS	LC	Voltage, Current	SPWM	abc-dq	Dual loop	Repetitive	Digital
[104]	General	LCL	Current	PWM	abc-	Single-loop	RC	Analog,Digital
[105]	PV	L	Power	PWM	abc	Dual loop	Fuzzy, NN	Digital

[106]	PV	L	Power	PWM	Three-phase,abc	Dual loop	Classic, NN	Analog,Digital
[112]	DG	LCL	Power, Voltage, Current	PWM	abc-	Dual loop	Autonomous	Analog

Table 1. Assessments on controllers

This table provides a useful starting point for selecting and presenting the required aspects of a control system to the reader. This table includes a variety of articles since it is thought that various approaches from previous sections may be employed in DPGS control systems. A combination of adaptive or robust approaches with other controllers is more often employed in recent papers. Some publications also advise combining RC with a fast controller in parallel or enhancing RC speed in other ways.

gital RC is a good option for most control systems in grid connected DPGS, based on an analysis of the control system characteristics and the fact that they are AC periodic loads. This controller's low speed, on the other hand, results in a slower dynamic reaction time for the

V. SIMULATION RESULTS AND DISCUSSION

In this section, simulation of grid connected converter with dq control method is discussed to control the real power and reactive power in system.

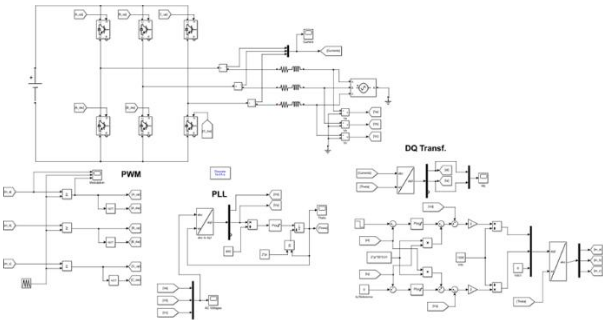


Figure 4. Real Power control of control of grid connected Inverter by dq control method

Figure 4 shows the Simulink model of real power control of grid connected inverter by dq control method. In this method real power of the grid is control by means of direct axis current control method. Direct axis current of the grid is compared with reference current and it is processed via PI controller and decoupled concept to generate the control signal for PWM generator. The PWM generator generates pulse for the inverter to control the real power on the inverter.

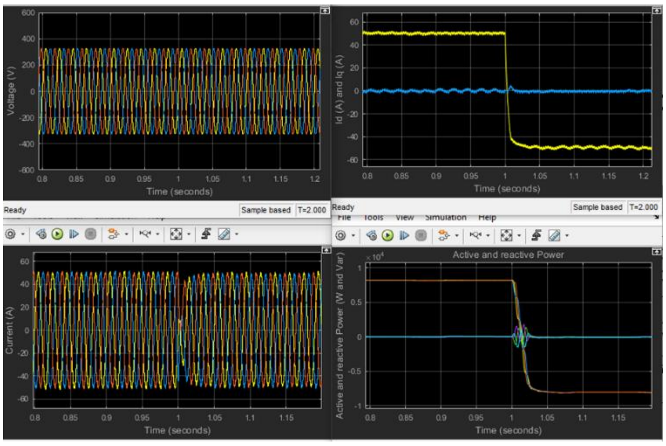


Figure 5. Results of Grid voltage, grid Current, Id & Iq current, Real and reactive power in the grid

Figure 5 show the results of grid voltage, current, Id and Iq current, real and reactive power of the grid. Reference current is maintained 50 A from 0 to 1 sec. after one second, *reference current is changed from 50 to -50 A and* corresponding results are presented in the Figure 5. From 0 to 1 sec, inverter supply the real power to the grid and after on second, grid supply the real power to inverter. Here real power is controlled effective in the system by means of dq control method.

Figure 6 shows the Simulink model of reactive power control of grid connected inverter by dq control method. In this method reactive power of the grid is control by means of quadrature axis current control method. quadrature axis current of the grid is compared with reference current generated from reactive power compensation system and it is processed via PI controller and decoupled concept to generate the control signal for PWM generator. The PWM generator generates pulse for the inverter to control the reactive power on the inverter.

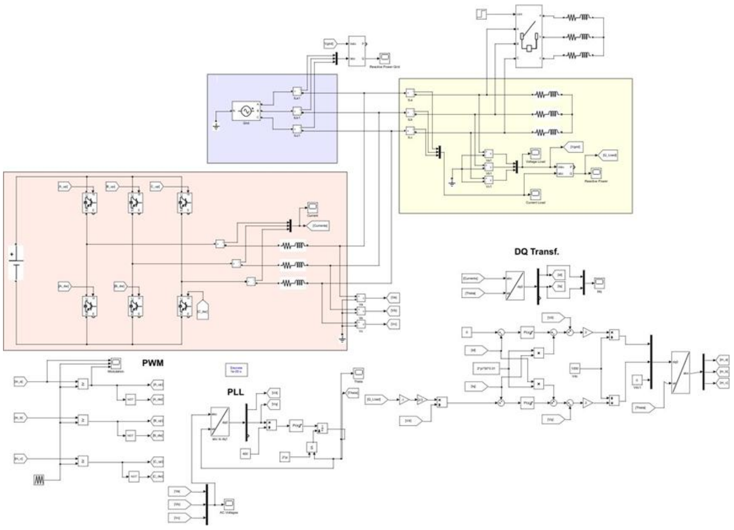


Figure 6. Reactive Power control of grid connected Inverter by dq control method

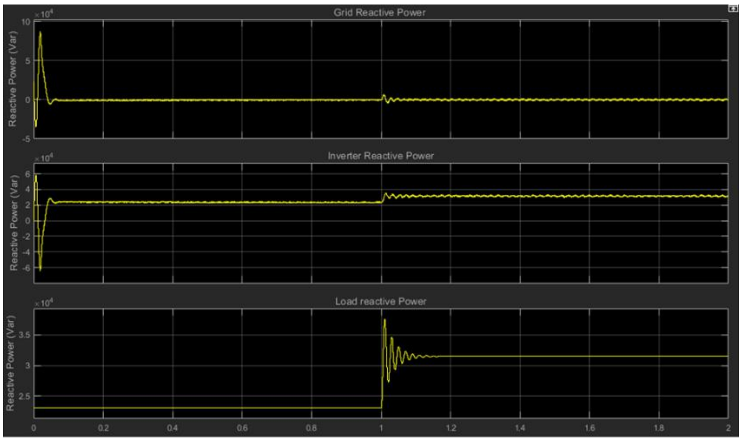


Figure 7. Reactive power of the gird, Inverter and Load

Figure 7 show the results of reactive power grid, inverter and load. Load reactive power is maintain at 24 kVAR from 0 to 1 sec. after one second, load reactive power is changed from 24 kVAR to -33 kVAR A and corresponding results are presented in the Figure 5. For both reactive power load condition, inverter only supply the reactive to the load and reactive power from grid is zero. And here reactive power of the inverter controlled effectively by means of dq control methods.

VI. CONCLUSION

Many distinct kinds of control systems have been investigated in this study, and the most essential characteristics of each of these systems have been classified and briefly described. It is important to remember that each feature should be chosen by the designer in accordance with his or her needs.

The key parameters must be selected based on the current state of the system and the anticipated duties performed by the control system. Power and control system configurations should then be developed.

System comparison and application were discussed in detail in the fourth part after a thorough study of the various systems. There were credible and fresh publications that employed robust or adaptable approaches with other controllers to meet the predicted tasks of the control system, which were discovered by comparison of various articles.

D-Q Control algorithm has proved better in controlling real and reactive power during grid-interconnection.

REFERENCES

[1] Blaabjerg F, Teodorescu R, Liserre M, Timbus AV. "*Overview of control and grid synchronization for distributed power generation systems",* IEEE Trans Ind Electron 2006;53(5):1398–409, [Oct.].

[2] "*The future role and challenges of energy storage, European Commission directorate-general for energy"*, DG ENER Work in paper, 2013.

[3] Miret J, Camacho A, Castilla M, Vicuna LG, Matas J. "*Control scheme with voltage support capability for distributed generation inverters under voltage sags"*. IEEE Trans Power Electron 2013;28(11):5252–62, [Nov.].

[4] Liu Z, Liu J, Zhao Y. "*A unified control strategy for three-phase inverter in distributed generation*", IEEE Trans Power Electron 2014;29(3):1176–91, [Mar.].

[5] Li Y, Jiang S, Rivera C, Peng FZ. "*Modeling and control of Quasi-Z-Source inverter for distributed generation applications",* IEEE Trans Ind Electron 2013;60(4):1532–41, [Apr.].

[6] Ebadi M, Joorabian M, Moghani JS. "*Voltage look-up table method to control multilevel cascaded transformerless inverters with unequal DC rail voltages*", IET Power Electron 2014;7(9):2300–9, [Sep.].

[7] Eren S, Pahlevani M, Bakhshai A, Jain P. "*An adaptive droop DC-bus voltage controller for a grid-connected voltage source inverter with LCL filter",* IEEE Trans Power Electron 2015;30(2):547–60, [Feb.].

[8] Abu-Rub H, Guzin´ski J, Krzeminski Z, Toliyat HA. "*Predictive current control of voltage- source inverters",* IEEE Trans Ind Electron 2004;51(3), [Jun.].

[9] Espí MJ, Castelló J, García-Gil R, Garcerá G, Figueres E. "*An adaptive robust predictive current control for three-phase grid-connected inverters*", IEEE Trans Ind Electron 2011;58(8), [Aug.].

[10] Moreno JC, Huerta JME, Gil RG, Gonzalez SA. "*A robust predictive current control for three-phase grid-connected inverters",* IEEE Trans Ind Electron 2009;56(6):1993–2004, [Jun.].

[11] Ahmed KH, Massoud AM, Finney SJ, Williams BW. "*A modified stationary reference frame-based predictive current control with zero steady-state error for LCL coupled inverter- based distributed generation systems"*, IEEE Trans Ind Electron 2011;58(4):1359–70, [April].

[12] Miveh MR, Rahmat MF, Ghadimi A, Mustafa M. "*Control techniques for three phase four- leg voltage source inverters in autonomous microgrids: a review",* Renew Sustain Energy Rev 2016;54:1592–610, [Feb.].

[13] Lettl J, Bauer J, Linhart L. "*Comparison of different filter types for grid-connected inverter*", PIERS Proceedings, Marrakesh, Morocco, 2011, pp. 20–23.

[14] Niroomand M, Karshenas HR. "*Review and comparison of control methods for uninterruptible power supplies*", In: 1st power electronic and drive systems and technologies conference, 2010.

[15] Kumar KV, Michael PA, John JP, Kumar SS. "Simulation and comparison of SPWM and SVPWM control for three phase inverters", ARPN J Eng Appl Sci 2010;5(7), [July].

[16] Monica P, Kowsalya M. "*Control strategies of parallel operated inverters in renewable energy application: a review*", Renew Sustain Energy Rev 2016; 65:885–901, [Nov.].

[17] Samui A, Samantaray SR. "New active islanding detection scheme for constant power and constant current controlled inverter-based distributed generation", IET Gener Transm Distrib 2013;7(7):779–89, [July].

[18] Yuan X, Merk W, Stemmler H, Allmeling J. "*Stationary-frame generalized integrators for current control of active power filters with zero steady-state error for current harmonics of concern under unbalanced and distorted operating conditions*", IEEE Trans Ind Appl 2002;38(2):523–32, [April].

[19] Miret J, Castilla M, Matas J, Guerrero JM, Vasquez JC. "*Selective harmonic compensation control for single-phase active power filter with high harmonic rejection",* IEEE Trans Ind Electron 2009;56(8), [Aug].

[20] Zeng Q, Chang L, Song P. "*SVPWM-based current controller with grid harmonic compensation for three-phase grid-connected VSI*", In: IEEE 35th annual power electronics specialists conference. Vol. 4. 2004, pp. 2494–2500.

[21] Lee KJ, Park NJ, Hyun DS. *"Optimal current controller in a three-phase grid connected inverter with an LCL filter*", In: ICPE 7th international conference on power electronics. 2007, pp. 568–571.

[22] Kandil MS, El-Saadawi MM, Hassan AE, Abo-Al-Ez KM. "*A proposed reactive power controller for DG grid-connected systems*", IEEE Int Energy Conf Exhib 2010:446–51, [Dec.].

[23] Beza M, Bongiorno M. "*Improved discrete current controller for grid-connected voltage source converters in distorted grids",* IEEE Energy Convers Congr Expo 2012:77–84, [Sept.].

[24] Xiongfei W, Blaabjerg F, Zhe Ch. "*A current controller of grid-connected converter for harmonic damping in a distribution network*", In: International conference on electrical machines and systems. 2011. pp. 1–6.

[25] Park SJ, Park JH, Jeon HJ. "*Controller design of grid-connected power conditioning system with energy storage device*", In: International conference on electrical machines and systems. 2011. pp. 1–6.

[26] Zhang H, Hongwei Z, Ren J, Liu W, Ruan S, Gao Y. "*Three-phase grid-connected photovoltaic system with SVPWM current controller",* In: IEEE 6th international power electronics and motion control conference. 2009. pp. 2161–2164.

[27] Chilipi R, Al Sayari N, Al Hosani K, Beig AR. "*Control scheme for grid-tied distributed generation inverter under unbalanced and distorted utility conditions with power quality ancillary services",* IET Renew Power Gener 2016;10(2):140–9, [Feb].

[28] Radwan AA, Mohamed YA, "*Power synchronization control for grid-connected current- source inverter-based photovoltaic systems*", IEEE Trans Energy Convers 2016;31(3):1023–36, [Sept.].

[29] Teodorescu R, Blaabjerg F, Liserre M, Loh PC. "*Proportional-*

resonant controllers and filters for grid-connected voltage-source converters”, IEEE Proc Electr Power Appl 2006;153(5):750–62, [Sept.].

[30] Xu J, Xie S, Tang T, “*Active damping-based control for grid-connected lcl-filtered inverter with injected grid current feedback only”,* IEEE Trans Ind Electron 2014;61(9):.4746–4758, [Sept.].

[31] Geng H, Xu D, Wu B, Yang G, “*Active islanding detection for inverter-based distributed generation systems with power control interface*”, IEEE Trans Energy Convers 2011;26(4):1063–72, [Dec.].

[32] Camacho A, Castilla M, Miret J, Vasquez JC, Alarcon-Gallo E , “*Flexible voltage support control for three-phase distributed generation inverters under grid fault*”, IEEE Trans Ind Electron 2013;60(4):1429–41, [April].

[33] Lee TL, Hu SH. “*Resonant current compensator with enhancement of harmonic impedance for LCL-filter based active rectifiers”,* In: Proc. IEEE APEC. 2011. pp. 1538–1543.

[34] Castilla M, Miret J, Matas J, Garcia de Vicuna L, Guerrero JM, “*Linear current control scheme with series resonant harmonic compensator for single-phase grid connected photovoltaic inverters*”, IEEE Trans Ind Electron 2008;55(7):2724–33, [Jul.].

[35] Castilla M, Miret J, Camacho A, Matas J, García de Vicuña L. “*Reduction of current harmonic distortion in three-phase grid-connected photovoltaic inverters via resonant current control*”, IEEE Trans Ind Electron 2013;60(4), [April].

[36] Shen G, Zhu X, Xu D. “*A new feedback method for PR current control of LCL-filter based grid-connected inverter*”, IEEE Trans Ind Electron 2010;57(6), [June].

[37] Ch Bao, Ruan X, Wang X, Li W, Pan D, Weng K. “*Step-by-step controller design for LCL- type grid-connected inverter with capacitor–current-feedback active-damping*”, IEEE Trans Power Electron 2014;29(3):1239–53, [March].

[38] Gaafar MA, Shoyama M. “*Active damping for grid connected LCL filter based on optimum P+R controller design using injected grid current feedback only*”, In: IEEE 36th international telecommunications energy conference. 2014. pp. 1–6.

[39] Hwang JWG, Winkelnkemper M, Lehn PW. “*Design of an optimal stationary frame controller for grid-connected AC-DC converters*”, In: 32nd Annual conference on IEEE industrial electronics. 2006. pp. 167–172.

[40] Zeng G, Rasmussen TW. “*Design of current-controller with PR-regulator for LCL filter- based grid-connected converter*”, In: 2nd IEEE international symposium on power electronics for distributed generation systems. 2010. pp. 490–494.

[41] Mishra S, Achary BS. “A *novel controller for a grid-connected single phase PV system and its real time implementation*” , In: IEEE PES general meeting | conference and exposition. 2014. pp. 1–5.

[42] Athans M. “*The role and use of the stochastic Linear-Quadratic-Gaussian problem in control system design*”, IEEE Trans Autom Control 1971; AC-16:529–52.

[43] Huerta F, Pizarro D, Cobreces S, Rodriguez FJ, Girón C, Rodriguez A., *“LQG servo controller for the current control of LCL grid-connected voltage-source converters*”, IEEE Trans Ind Electron 2012;59(11):4272–84, [Nov].

[44] Busada C, Gómez Jorge S, Leon AE, Solsona J. “*Phase-locked loop-less current controller for grid-connected photovoltaic systems*”, IET Renew Power Gener 2012;6(6):400–7, [November].

[45] Komurcugil H. “*Rotating-sliding-line-based sliding-mode control for single-phase UPS inverters*”, IEEE Trans Ind Electron 2012;59(10):3719–26, [Oct.].

[46] Yarahmadi S, Arab Markade Gh.R, Soltani J. *”Current harmonics reduction of nonlinear load by using active power filter based on improved sliding mode control”,* In: 4th power electronics, drive systems and technologies conference. 2013.

[47] Sun Y, Qian M, Lin Y, Bai Zh. “*A fuzzy-sliding mode controller for four-quadrant PWM converter of grid-connected wind generation simulator*”, In: International conference on consumer electronics, communications, and networks. 2011. pp. 3827–3830.

[48] Bouaziz B, Bacha F. “*Direct power control of grid-connected converters using sliding mode controller*”, In: International conference on electrical engineering and software applications. 2013. pp. 1–6.

[49] Hao X, Liu T, Yang X, Huang L. *“A discrete-time integral sliding-mode controller with nonlinearity compensation for three-phase grid-connected photovoltaic inverter”,* In: 7th International power electronics and motion control conference. Vol. 2. 2012. pp. 831–835.

[50] Kumar N, Saha TK, Dey J. “*Sliding-mode control of PWM dual inverter-based grid connected PV system: modeling and performance analysis*”, IEEE J Emerg Sel Top Power Electron 2016;4(2):435–44, [June].

[51] Mahmud MA, Pota HR, Hossain MJ. *“Nonlinear controller design for single-phase grid- connected photovoltaic systems using partial feedback linearization”*, In: 2nd Australian control conference. 2012, pp. 30–35.

[52] Mahmud MA, Pota HR, Hossain MJ, Roy NK. “*Robust nonlinear controller design for three-phase grid-connected photovoltaic systems under structured uncertainties*”. IEEE Trans Power Deliv 2014;29(3):1221–30, [June].

[53] Yao Zh, Xiao L. “*Control of single-phase grid-connected inverters with nonlinear loads*”, IEEE Trans Ind Electron 2013;60(4), [April].

[54] Ho CNM, Cheung V, Chung HSH. “*Constant-frequency hysteresis current control of grid- connected VSI without bandwidth control”,* IEEE Trans Power Electron 2009;24(11):2484–95, [Nov.].

[55] Li Y, Hao X, Yang X, Xie R, Liu T. *“A variable-band hysteresis modulated multiresonant sliding-mode controller for three-phase grid-connected VSI with an LCL filter”,* IEEE ECCE Asia Down Under 2013:670–4, [June].

[56] Jena S, Babu BC. “*Power quality improvement of 1-Φ grid-connected PWM inverter using fuzzy with hysteresis current controller*”, In: 10th International conference on environment and electrical engineering. 2011. pp. 1–4.

[57] Ichikawa R, Funato H. “*Single phase utility interface inverter based on digital hysteresis current controller - Operational characteristics both grid-connected mode and islanding mode*”, In: 15th International power electronics and motion control conference, 2012, pp. LS8b.3-1– LS8b.3-8.

[58] Zhang X, Wang Y, Yu C, Guo L, Cao R. “*Hysteresis model predictive control for high- power grid-connected inverters with output LCL filter*”, IEEE Trans Ind Electron 2016;63(1):246–56, [Jan.].

[59] Damen A, Weiland S. “*Robust Control*”, Measurement and Control Group Department of Electrical Engineering Eindhoven University of Technology P.O. Box 513, Draft version, July 2002.

[60] Zames G. “*Feedback and optimal sensitivity: model reference transformations, multiplicative seminorms, and approximate inverses*”, IEEE Trans Autom Control 1981:301– 20.

[61] Hornik T, Zhong Q Ch. “*A current-control strategy for voltage-source inverters in microgrids based on H∞ and repetitive control*”, IEEE Trans Power Electron 2011;26(3), [March].

[62] Yang S, Lei Q, Peng FZ, Qian Z. “*A robust control scheme for grid-connected voltage source inverters*”, IEEE Trans Ind Electron. 2010.

[63] Chhabra M, Barnes F, “*Robust current controller design using mu-synthesis for grid- connected three phase inverters*”, In: IEEE 40th Photovoltaic Specialist Conference. 2014. pp. 1413–1418.

[64] Hornik T, Zhong QC. *“H∞ repetitive current controller for grid-connected inverters”,* In: 35th Annual Conference of IEEE Industrial Electronics. 2009. pp. 554–559.

[65] Chen T, Malik OP. “*Power system stabilizer design using mu-synthesis*”, IEEE Trans. Energy Convers. 1995.

[66] Sun X, Tian Y, Chen, Zh. “*Adaptive decoupled power control method for inverter connected DG*”, IET Renew Power Gener 2014;8(2):171–82, [March].

[67] Do TD, Leu VQ, Choi YS, Choi HH, Jung JW. *“An adaptive voltage control strategy of three-phase inverter for stand-alone distributed generation systems”*, IEEE Trans Ind Electron 2013;60(12):5660–72, [Dec.].

[68] Jung JW, Vu NTT, Dang DQ, Do TD, Choi YS, Choi HH. “*A three-*

phase inverter for a standalone distributed generation system: adaptive voltage control design and stability analysis", IEEE Trans Energy Convers 2014;29(1):46–56, [March].

[69] Timbus AV, Ciobotaru M, Teodorescu R, Blaabjerg F. *"Adaptive resonant controller for grid-connected converters in distributed power generation systems"*, In: APEC '06. Twenty-First Annual IEEE applied power electronics conference and exposition. 2006. pp. 6 pp.

[70] Mascioli M, Pahlevani M, Jain PK. *"Frequency-adaptive current controller for grid connected renewable energy systems"*, In: IEEE 36th International telecommunications energy conference (INTELEC). 2014. pp. 1–6.

[71] Guo Q, Wang J, Ma H. *"Frequency adaptive repetitive controller for grid-connected inverter with an all-pass infinite impulse response (IIR) filter*", In: IEEE 23rd International symposium on industrial electronics (ISIE). 2014. pp. 491–496.

[72] Jorge SG, Busada CA, Solsona JA. "Frequency-adaptive current controller for three-phase grid-connected converters", IEEE Trans Ind Electron 2013;60(10):4169–77, [Oct.].

[73] Lim JS, Park Ch, Han J, Lee YI. "*Robust tracking control of a three-phase DC–AC inverter for UPS applications"*, IEEE Trans Ind Electron. Vol. 61, no. 8, 2014. pp. 4142– 4151.

[74] Zeng Q, Chang L. *"Improved current controller based on SVPWM for three-phase grid- connected voltage source inverters"*, In: IEEE 36th PESC '05 Power Electronics Specialists Conference. 2005. pp. 2912–2917.

[75] Zeng Q, Chang L. "*Development of an SVPWM-based predictive current controller for three-phase grid-connected VSI"*, in Industry Applications Conference, 2005. Fourtieth IAS Annual Meeting. Conference Record of the 2005. Vol. 4. 2005. pp. 2395–2400.

[76] Ouchen S, Betka A, Abdeddaim S, Menadi A. "*Fuzzy-predictive direct power control implementation of a grid connected photovoltaic system, associated with an active power filter"*, Energy Convers Manag 2016;122(15):515–25, [August].

[77] Ouchen S, Abdeddaim S, Betka A, Menadi A. *"Experimental validation of sliding mode- predictive direct power control of a grid connected photovoltaic system, feeding a nonlinear load. Sol Energy*", 2016;137(1):328–36, [November].

[78] Huerta JME, Castello J, Fischer JR, Garcia-Gil R. "*A synchronous reference frame robust predictive current control for three-phase grid-connected inverters"*, IEEE Trans Ind Electron 2010;57(3):954–62, [Mar.].

[79] Mohamed YR, El-Saadany E. "*An improved deadbeat current control scheme with a novel adaptive self-tuning load model for a three-phase PWM voltage-source inverter*", IEEE Trans Ind Electron 2007;54(2):747–59, [Apr.].

[80] Mattavelli P. "*An improved deadbeat control for UPS using disturbance observers*", IEEE Trans Ind Electron 2005;52(1), [Feb.].

[81] Zeng Q, Chang L. "*An advanced SVPWM-based predictive current controller for three- phase inverters in distributed generation systems"*, IEEE Trans Ind Electron 2008;55(3), [March].

[82] Bode GH, Loh PC, Newman MJ, Holmes DG. "*An improved robust predictive current regulation algorithm"*,in The Fifth international conference on power electronics and drive systems, PEDS 2003. Vol. 2, 2003. pp. 1058–1063.

[83] Niroomand M, Karshenas HR. *"Hybrid learning control strategy for three-phase uninterruptible power supply*", IET Power Electron 2011;4(7):799–807, [Aug.].

[84] Tan KT, So PL, Chu YC, Chen MZQ. "*Coordinated control and energy management of distributed generation inverters in a microgrid*", IEEE Trans Power Deliv 2013;28(2):704–13, [April].

[85] Tan KT, Peng XY, So PL, Chu YC, Chen MZQ. "Centralized control for parallel operation of distributed generation inverters in microgrids", IEEE Trans Smart Grid 2012;3(4):1977–87, [Dec.].

[86] Mariethozand S, Morari M. Explicit model-predictive control of a PWM inverter with an LCL filter. IEEE Trans Ind Electron 2009;56(2):389–99, [Feb.].

[87] Rodríguez J, Pontt J, Silva CA, Correa P, Lezana P, Cortés P, Ammann U. "*Predictive current control of a voltage source inverter*", Ind Electron, IEEE Trans on 2007;54(1), [Feb.].

[88] Sosa JM, Martinez-Rodriguez PR, Vazquez G, Serrano JP, Escobar G, ValdezFernandez AA. "*Model based controller for an LCL coupling filter for transformerless grid-connected inverters in PV applications",* In: 39th Annual Conference of the IEEE Industrial Electronics Society, IECON 2013. 2013. pp. 1723–1728.

[89] Krishna R, Kottayil SK, Leijon M. "*Predictive current controller for a grid connected three level inverter with reactive power control*", In: IEEE 12th workshop on control and modeling for power electronics (COMPEL). 2010. pp. 1–6.

[90] Ayad AF, Kennel RM. "*Model predictive controller for grid-connected photovoltaic based on quasi-Z-source inverter*", In: IEEE international symposium on sensorless control for electrical drives and predictive control of electrical drives and power electronics (SLED/PRECEDE). 2013. pp. 1–6.

[91] Lee KJ, Park BG, Kim RY, Hyun DS. *"Robust predictive current controller based on a disturbance estimator in a three-phase grid-connected inverter"*, IEEE Trans Power Electron 2012;27(1):276–83, [Jan.].

[92] Trabelsi M, Ghazi KA, Al-Emadi N, Ben-Brahim L. "*An original controller design for a grid-connected PV system,"* IECON 2012 - In: Proceedings of the 38th Annual Conference on IEEE Industrial Electronics Society, vol., no., pp.924,929, 25–28 Oct; 2012.

[93] Trabelsi M, Ghazi KA, Al-Emadi N, Ben-Brahim L. "*An original controller design for a grid-connected PV system*", In: IECON 2012 - 38th Annual Conference on IEEE Industrial Electronics Society. 2012. pp. 924, 929.

[94] Sathiyanarayanan T, Mishra S. "*Synchronous reference frame theory-based model predictive control for grid connected photovoltaic systems"*, IFAC-Pap on Line 2016;49(1):766–71.

[95] Passino KM. "*Intelligent control: anan overview of techniques. Department of Electrical Engineering"*, Ohio State University; 2015.

[96] Bojoi R, Limongi LR, Roiu D, Tenconi A. *"Enhanced power quality control strategy for single-phase inverters in distributed generation systems"*, IEEE Trans Power Electron 2011;26(3):798–806, [March].

[97] de Almeida PM, Duarte JL, Ribeiro PF, Barbosa PG. *"Repetitive controller for improving grid-connected photovoltaic systems"*, IET Power Electron 2014;7(6):1466–74, [June].

[98] Ramos C, Martins A, Carvalho A. *"Complex state-space current controller for gridconnected converters with an LCL filter"*, In: 35th Annual conference of IEEE industrial electronics, IECON '09. 2009. pp. 296–301.

[99] Kalaiselvi K. "*Development of power flow controller for grid-connected renewable energy sources using lyapnouv function*", In: 2014 International conference on green computing communication and electrical engineering (ICGCCEE). 2014. pp. 1–7.

[100] Jamil M, Arshad R, Rashid U, Ayaz Y, Khan MN. "*Design and analysis of repetitive controllers for grid-connected inverter considering plant bandwidth for interfacing renewable energy sources*", In: 2014 International conference on renewable energy research and application (ICRERA). 2014. pp. 468–473.

[101] Liu T, Wang D. *"Parallel structure fractional repetitive control for PWM inverters"*, IEEE Trans Ind Electron 2015; vol (99), [pp.1,1].

[102] Nazir R, Zhou K, Watson NR, Wood A. "*Frequency adaptive repetitive control of grid- connected inverters*", In: 2014 International conference on control, decision, and information technologies (CoDIT). 2014. pp. 584–588.

[103] Jiang Sh, Cao D, Li Y, Liu J, Peng FZh. *"Low-THD, fast-transient, and cost-effective synchronous-frame repetitive controller for three-phase UPS inverters"*, IEEE Trans Power Electron 2012;27(6):2994–3005, [June].

[104] Zhao Q, Ye Y, Xu G, Zhu M. "*Improved repetitive control scheme for grid connected inverter with frequency adaptation*", IET Power Electron 2016;9(5):883–90, [4 20].

[105] Lin FJ, Ch. Lu K, Ke TH. *"Probabilistic Wavelet Fuzzy Neural Network based reactive power control for grid-connected three-phase PV system during grid faults*", Renew Energy 2016;92:437–49, [July].

[106] Kyoungsoo R, Rahman S. *"Two-loop controller for maximizing performance of a grid- connected photovoltaic-fuel cell hybrid power plant*", IEEE Trans Energy Convers 1998;13(3):276–81, [Sep].

[107] Thiagarajan Y, Sivakumaran TS, Sanjeevikumar P. *"Design and simulation of fuzzy controller for a grid-connected standalone PV system*", In: 2008 International conference on computing, communication and networking, ICCCn. 2008. pp. 1–6.

[108] Thao NGM, Dat MT, Binh TC, Phuc NH. "*PID-fuzzy logic hybrid controller for gridconnected photovoltaic inverters*", In: 2010 International forum on strategic technology (IFOST). 2010. pp. 140–144.

[109] Zhao R, Zhenguo Ch, Peie Y, Liyong Y, Zhengxi L. "*A novel fuzzy logic and antiwindup PI controller for three-phase grid-connected inverter*", In: 2009 2nd International conference on power electronics and intelligent transportation system (PEITS). Vol. 1. 2009. pp. 442–446.

[110] Shareef H, Mohamed A, Mutlag AH. "*A current control strategy for a grid connected PV system using fuzzy logic controller*", In: 2014 IEEE international conference on industrial technology (ICIT). 2014. pp. 890–894.

[111] Thakare SG, Dalvi HS, Joshi KD. *"Statcom based fuzzy controller for grid connected wind generator",* In: 2009 2nd International conference on emerging trends in engineering and technology (ICETET). 2009. pp. 35–39.

[112] Wang X, Blaabjerg F, Chen Z. *"Autonomous control of inverter-interfaced distributed generation units for harmonic current filtering and resonance damping in an islanded microgrid*", IEEE Trans Ind Appl 2014;50(1):452–61, [Jan.- Feb.].