INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH
B. Srikanth Goud et al., Vol.10, No.2, June, 2020

Essentials for Grid Integration of Hybrid Renewable Energy Systems: A Brief Review

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Received: 10.04.2020 Accepted: 07.05.2020

Abstract- High penetration of alternative energy sources is increasing in daily life to meet the world's energy consumption demand. Moreover, there are several issues related to grid integration of HRES keeping in the view of recent trends it becomes necessary to investigate the possible solutions for these issues. Power electronic pieces of equipment place a major role in power quality issues of integrated systems if the major part of power is supplied by renewable sources. This paper reviews the requirements for the proper integration of HRES to the grid. Majorly it concentrates on the review of DC/DC converters, Inverters, Control techniques, and Power quality issues when HRES are connected to the grid. The advantages, disadvantages, and applications of each method or technique are described in detail.

Keywords DC/DC Converters, HRES, Multilevel Inverters, Controllers, Power Quality Issues

1. Introduction

In recent years, power system networks have experienced many problems such as the utilization of fossil fuels and thermal generation which generates the power with critical factor emissions that are depleting fuel, expensive and pollution [1]. Renewable energy resources (RES) have the ability to overcome limitations of conventional resources such as global warming and pollution etc. [2]. The worldwide take consideration of power safety, global warming and environmental problems is an essential part of enabling the flexibility and stability in the power system. When using RES in the power system which produces a high increase rate of stability and flexibility conditions. The distribution systems and transmission systems also affect the stability condition due to the penetration of RES [3]. Because the transmission systems and distribution systems experience continuous evolution from RES, it is required to coordinate and monitoring of the system for enabling safe operation, stability maintenance, consistent and effective operation. The continuous monitoring of the system with RES provides good efficiency. The RES system efficiency can be increased with the control of power electronic devices in the power system [4]. RES operation surely affects the usage of hybrid research. The combination of one or more renewable resources connected in the system describes the Hybrid system. The hybrid RES (HRES) can be coupled with a distributed system to meet load requirements. From the RES, Photovoltaic (PV) and wind energy conversion systems (WECS) are the most advanced renewable resources. The HRES is connected in distribution systems creates the problem of instability condition [5]. Especially power quality issues will be increased in the system such as sag, swell, disturbances, interruption, harmonics and so on. Due to power quality issues, the voltage level of the distribution system will be oscillating and creates a tripping problem. The reliability of the system totally affected due to the occurrence of continuous tripping behavior [6]. Tripping problems can be recovered by operating grid standards. In the power system issues like power quality, voltage sag and swell are considered as main problems. The voltage sag and swell create the power on the consumer side by providing low power from HRES which will affect the power electronic devices and loads. These power quality issues can be overcome by Flexible AC transmission systems (FACT) devices and filters in the power system [7]. Numerous devices are available and divided on the basis of series devices and shunt devices. The series devices (SSSC and DVR) that compensate the voltage in REG based distribution systems. Similarly, shunt devices (STATCOM, DSTATCOM and TCR) compensate for the voltage in a distribution system [8]. The FACT device compensates for the power quality issues by injecting the required voltage level and maintains a stable voltage level. DSTATCOM has two control modes, regulate the load voltage in voltage control mode and another one is injected reactive and harmonic components in current mode [9, 10]. The FACT device also controlled with an essential control technique to manage stability conditions in distribution systems. The proper control must be required to avoid power quality issues and maintain stable conditions with HRES based distribution systems.

2. Brief review of HRES

Francois Giraud, Zyiad M. Salameh [11] has investigated the integration of Wind-PV power system and the system performance with energy storing and concluded that wind is best potential source than solar and provides energy during the absence of solar energy. M. Amir and S. K. Srivastava [12] has proposed grid integration of PV Wind with HC MPPT control algorithms and operation of the inverter using Fuzzy logic based controller. Additionally, the battery source is employed for energy storage in case of emergency to supply to the grid as well as variable loads. J. Arkhangelski *et al.* [13] proposed HRES grid integration using multiple control systems for current control, reductions and Power quality improvement M. Naresh *et al.* [14] introduced Neuro-fuzzy system in DFIG operated wind energy conversion systems for better power quality improvement by PLL synchronization using reference frequency produced in the system. Muthukumar and P. Balamurugan [15] developed an architecture for power quality improvement and stability by using predictive controllers by developing a three-level inverter that improves the power factor of the developed system [75].

2.1 Photovoltaic Technology:

Solar Energy is available abundant in nature all over the world and playing an important role in the conversion of energy which is in the form of irradiance into electrical energy which is free from pollution using promising technology called Photo Voltaic. This technology is especially more useful in rural areas where there is no possibility of generation, transmission and distribution of energy which makes use of conventional sources. The structure of direct coupled PV system is shown in Fig.1.

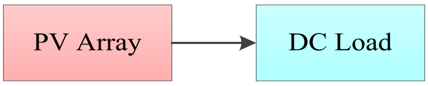

Fig. 1: Structure of Direct Coupled PV System

2.2 Standalone Photovoltaic system:

Independently operated systems generally called Direct-coupled systems. This function only during the hours of sunlight and the energy produced is directly converted into electrical energy with the usage of PV panels there are no external storage devices like batteries as depicted in Fig.2. They are used in various applications like DC fans, Water pumps, Solar thermal water heating, Room heaters [16-17].

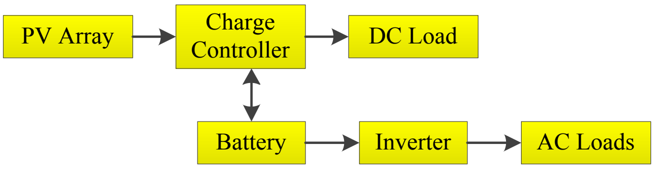

Fig. 2: Structure of Standalone PV System

2.3 Grid Connected PV system:

The architecture of the model is to function in parallel and attached to the utility grid system as shown in Fig.3. Many MPPT techniques have been introduced and improved for the purpose of tracking maximum power as solar energy is intermittent in nature. MPPT such as IC, P&O, PSO, CS, GA, GSA, BBO, ESA etc. studies in the literature [16], have been introduced. These techniques introduce the best value which either increases or decreases till the best operating point is produced [76]. They continuously compare with the previous values until the fitness of a new one cooperates with the optimization to decide on the command output value. This technique some time doesn't use as an exact technique to track MPPT reason for this as the best value is utilized which is mainly fixed by trails and tests running.

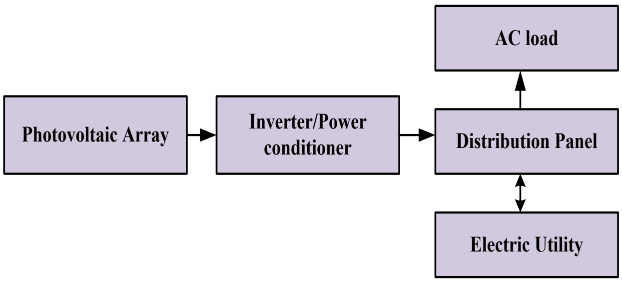

Fig. 3: Architecture of Grid Connected PV system

In order to convert the DC which is produced as an output from the PV into AC, we consider inverters with the required magnitude of voltage for better power quality at the grid an interface is made in between the PV and electric utility either to supply or feedback the grid when the output generated from PV is higher than the requirement of demand from load side.

2.4 Wind Turbine Technology:

2.4.1. Wind Turbine Technology Review

The drastic transformation of usage, wind turbine technologies are rapidly increased from the past 20 years. It extracts the natural heavy blown airs and then converts the motion of air into mechanical energy. They are generally produced due to the difference in their pressure. Speed may vary depending upon the atmospheric and geographical conditions. Generally, they are higher at the offshore and coast. Wind energy is gaining more popularity as a global electricity supply. The power generated from wind is quite different from the energy generated using fossil fuels with synchronous generators.

Most commonly used wind turbines are as follows

i) Doubly Fed Induction Generator
ii) Squirrel cage Induction Generator

i. *Doubly Fed Induction Generator:*

Generally, the rotor winding is connected to the converter slip ring and stator winding is directly connected directly to the grid as shown in Fig.4. This system is called variable-speed and has merits compared with the fixed speed technology because their yearly production of energy is higher, less stress and fast power failure since the rotor acts as a flywheel. It is also having demerit such as it requires converters which is cost-effective around 7% of the whole wind turbine and there are also energy losses at the rotor external resistance, Reactive power control is also difficult [16-17]

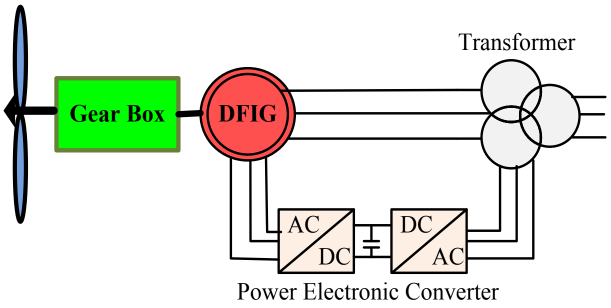

Fig. 4: Block Diagram of DFIG

ii. *Squirrel cage Induction Generator:*

SCIG is generally used as a constant-speed generator which has various stages. Primary is the wind form with low voltage, secondary is distribution stage with intermediate voltage and the final stage is the transmission stage generally with more voltages. The design of SISG where the stator is connected to the grid and rotor is short-circuited. This design is generally open-loop control systems in which wind power rapidly raises and its produced power is fixed correspondingly as shown in Fig.5. The turbine rotates with high speed but there won't be any change in output power because SCIG rotates with fixed speed. Pitch angle control is the main controller which to control the speed of the turbine. The main demerit is the voltage drop in distribution lone which may affect overload problems, controlling of speed is not possible since generator runs at a constant speed, Reactive power compensation has to be done. Hence it is cheap in cost simple reliable operation. [16-17]

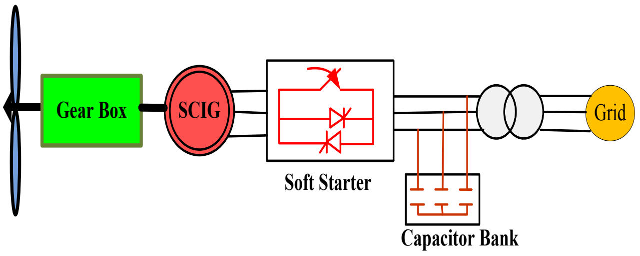

Fig. 5: Block diagram of SCIG

3. DC/DC Converters

Renewable power generation systems are more attracted by the government and industries because of their advantages like pollution-free and availability with free of cost. The DC/ DC converters place a vital role in the integration of PV and wind systems [18]. The researchers are very interested in designing various DC/DC for nonconventional energy source applications [72-73]. This section reviews various DC converter topologies which can provide better efficiency, good conversion ratio, less operating losses and low conduction losses.

3.1 Conventional boost converter

Fig.6 shows the design of a conventional boost converter which gives high voltage gain if its duty cycle is reached to one.

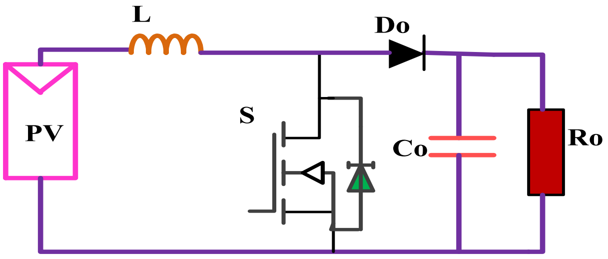

Fig.6: Single switch boost converter

High conduction losses and reverse recovery issues are caused due to the increase in the value of the duty cycle. Due to this overall efficiency of the system decreases. The limitations of this converter are current ripple, voltage stresses on transistors and increases recovery losses. Three-level converters provide double voltage gains when compared with the two-level inverter. It minimizes the voltage stresses, recovery losses and improves efficiency [19].

3.2 Interleaved step-up converter

A general step-up converter uses four interleaved boost converter configurations. This structure distributes the input current eventually; hence it reduces the switching losses and output voltage ripple [20]. An interleaved boost converter which reduces the input current ripple is the use of isolation transformer [21]. This structure uses the AC link. For improving the voltage gain it uses the voltage multiplier units as depicted in Fig. 7. Which helps for producing high voltage gain [22]. High voltage gain flyback converter uses the LC filters for filtering the harmonics which minimizes the voltage stresses of the switches [23].

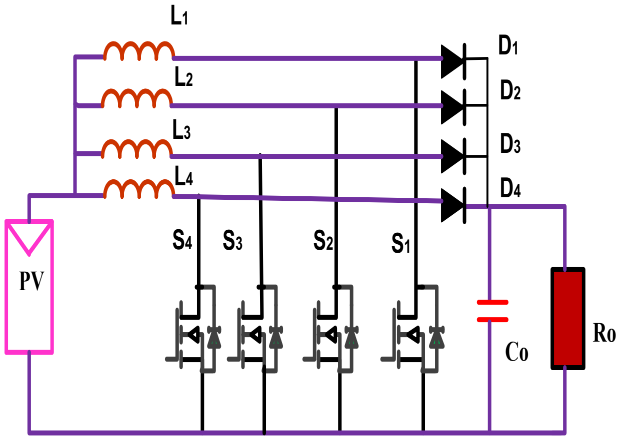

Fig.7: Interleaved boost converter

3.3 Soft switching high step up DC/DC Converter

Boost converters consist of switches and passive components. This converter uses soft switching techniques such as Zero Voltage Switching (ZVS) and Zero Current Switching (ZCS) for operating the switches.

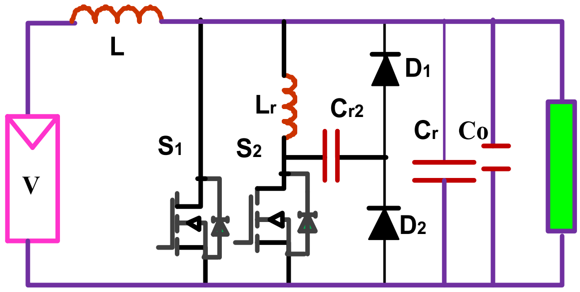

Fig.8: Soft switching ZCZVS boost converter

Due to the use of soft switching techniques, it can effectively eliminate the switching losses. The soft switching based high-performance boost converter is shown in Fig.8.

3.4 Coupled inductor based boost converter

The model generally acts like a transformer in Fig.9. It has better efficiency and good voltage gain. This structure can use voltage doubler circuits and active clamp circuits. To minimize the voltage stresses on the switches, primary passive clamp circuits are placed at the primary side [24]. Boost converter with voltage doubler feature is utilized to boost the voltages and to reduce the voltage stresses. Soft switching techniques are employed along with voltage doubler circuits to achieve high voltage gain, reduce stresses on switches by raising the turn's ratio of the system [25].

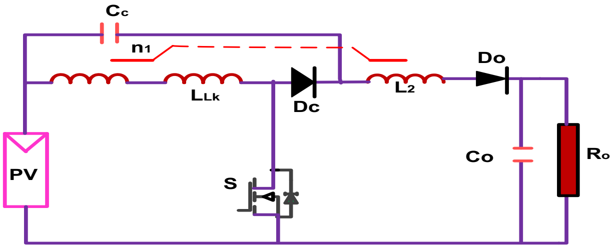

Fig.9: Coupled inductor based boost converter

3.5 Interleaved with voltage multiplier cell

The developed system is shown in Fig. 10, uses the current division technique. In classical interleaved boost converters MOSFET and voltage multiplier circuits are used for successfully reducing the harmonics in output voltage, turn-on losses and electromagnetic interference [26]. For high power applications, better performance and smaller size converters are required. This can be achieved by the utilization of clamp circuits and soft switching. It reduces the harmonics, voltage stresses and passive elements size [27].

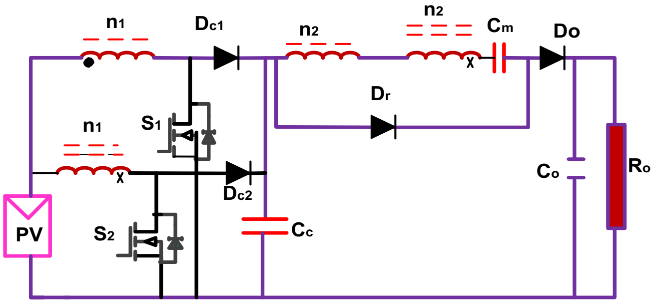

Fig.10: Interleaved boost converter with voltage multiplier cell

3.6 Isolated boost converter with coupled inverter

This structure uses a single magnetic circuit instead of individual magnetic circuits. Due to the assembling of all magnetic circuits into a single magnetic circuit, the size of the capacitor and inductor is decreased as in Fig.11. It is useful for a wind range of power applications. The disadvantage of this structure is it uses hard switching [28]. The structure with soft switching is used for low power applications that have low stress on switches and low harmonics [29].

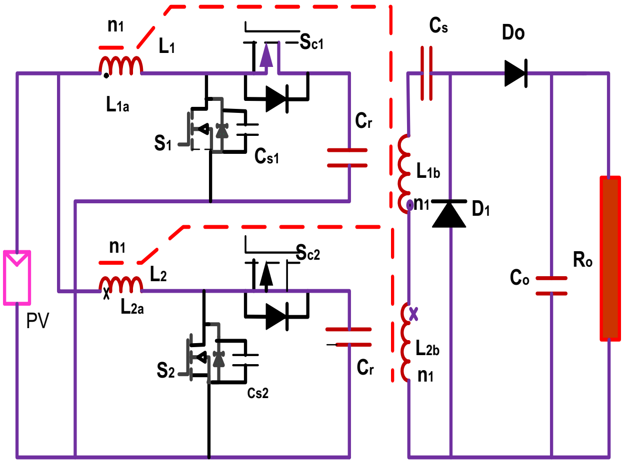

Fig.11: Isolated boost converter with coupled inductor

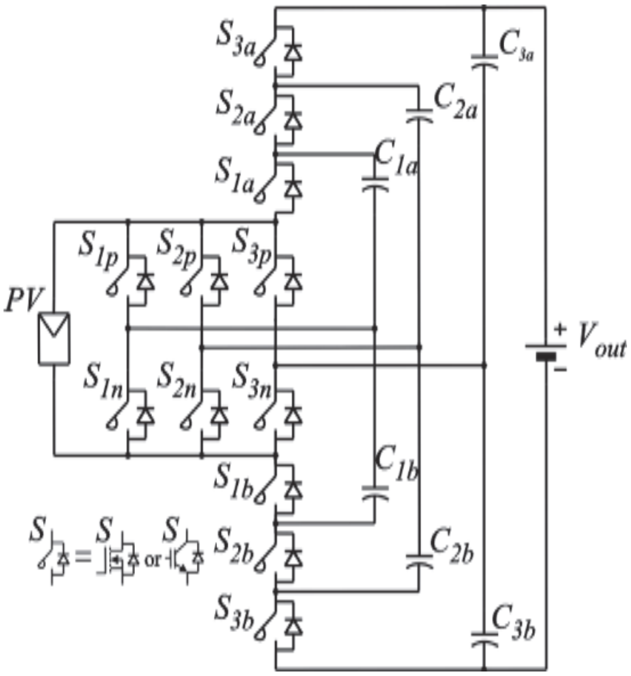

Fig.12: Multilevel switched capacitor boost converter

3.7 *Non-inductive boost converter*

This is a back to back multi-level DC/DC boost converter, which has six times of voltage conversion ratio. This structure performs buck and boost operations. It works as a buck converter when the power flow is reversed. It can operate at high temperatures because of the absence of inductor elements. It has advantages of high efficiency, good voltage regulation [30]. Capacitor coupled boost converter will operate at very high frequencies. It can also have bidirectional power flow and low voltage drop, which is depicted in Fig. 12.

3.8 *Basic isolated Boost converter topology*

There are many converters such as flyback converter, Zeta converter, push-pull, cuk and two inductor boost converter has provided more output gain but failed in providing higher efficiency. The active clamp boost converter is shown in Fig. 13. Have good output voltage, efficiency and synchronization with the DC link [31]. The resonant converter is shown in Fig. 14 uses the snubber configuration and voltage doublers for reducing on/off losses. The LC resonant converter output diode eliminates the reverse recovery issues, hence it is useful to use at various PV applications [32].

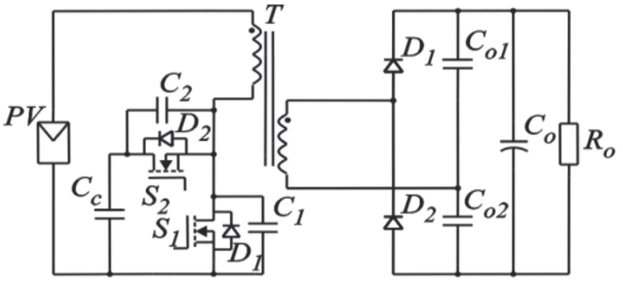

Fig.13: Active clamp boost converter

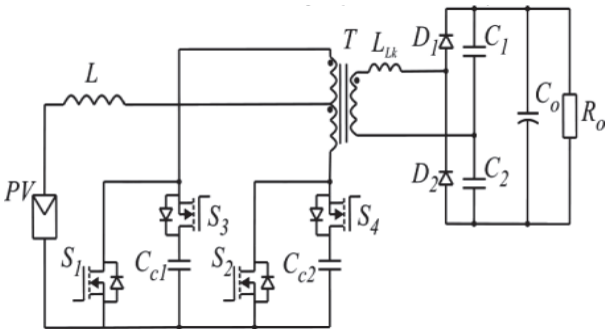

Fig.14: Push pull resonant boost converter

3.9 *Half bridge resonant converter*

For high out voltage generally current fed half bridge resonant converter utilized is shown in Fig. 15. In this structure due to the transformer turn off losses, the efficiency reduced [33]. To overcome this problem, the transformer leg diode is replaced with the leg capacitor. The leg capacitor effectively reduces the turns ratio and cost [34].

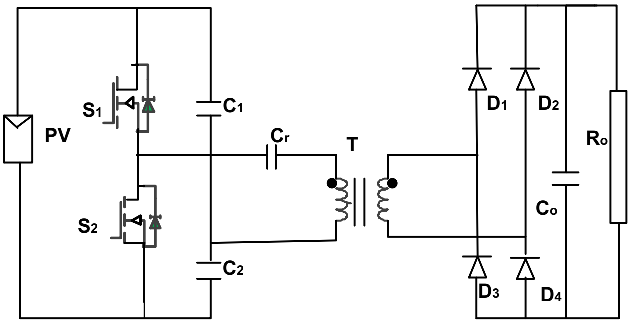

Fig. 15: Resonant half bridge boost converter

3.10 Non isolated converter with inbuilt transformer

High voltage gain of conventional converters is controlled by passive elements. Lowering the duty cycle reduces the efficiency and gain [35] [71]. To degrade this problem in traditional converters a novel technique is developed with a single switch three diode topology which is depicted in Fig. 16. This has the advantage of a good power factor correction circuit and smaller in weight [74].

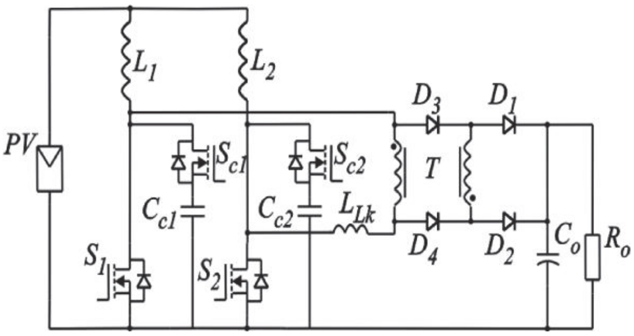

Fig.16: Non-isolated high step-up converter

4. Inverters

The two-level inverters produce more harmonic currents at the output which produces more losses. To overcome this problem multilevel inverters are developed. The multilevel inverters have the advantage of low harmonics at the output, pure sinusoidal voltage waveform, which can work at any frequency level; it has very low switching losses and good power quality [36]. The major drawback of such converters is the use of more number of switches [37]. Basically, there are three types of multilevel inverters as shown in Fig.17. This section presents the review of various multilevel inverters for grid integration of renewable sources as follows.

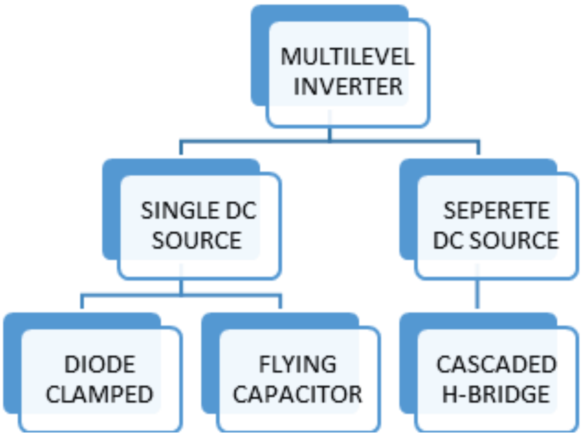

Fig.17: Classification of multilevel inverters

4.1 Diode clamped multilevel inverter

To clamp the voltage, they make use of diodes which is used to reduce the voltage stresses on the devices. The basic structure is as shown in Fig. 18. In reference [38] the proposed MLI is derived from the traditional inverter topology. This is an asymmetrical type of structure, which is realized with GTO and IGBT. The DC voltage is stabilized without inverter circuits [39]. It has more than three levels with a self voltage balancing procedure and implemented with more diodes, switches. The diode clamped MLI with STATCOM is presented in reference [40]. This compensates the reactive power and produces a unity power factor. For inverter with m levels, it needs 2 (n-1) switches, (n-1) voltage sources and (n-1) (n-2) clamping diodes.

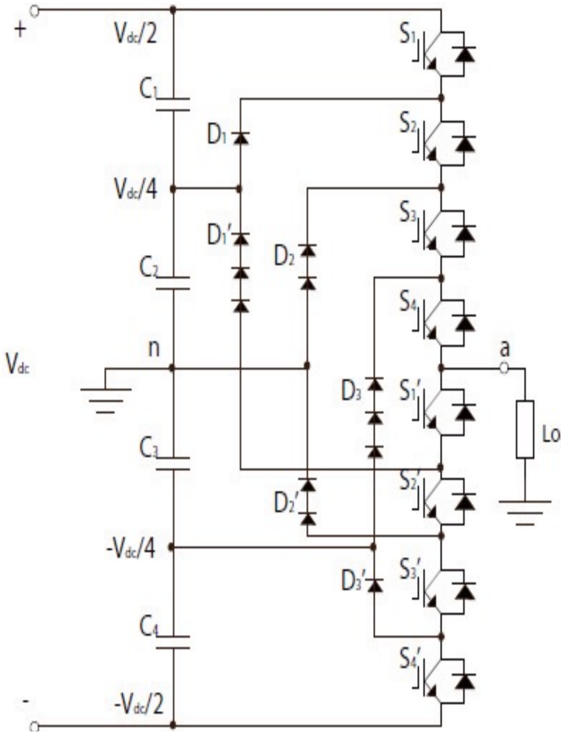

Fig.18: Single leg of diode clamped MLI

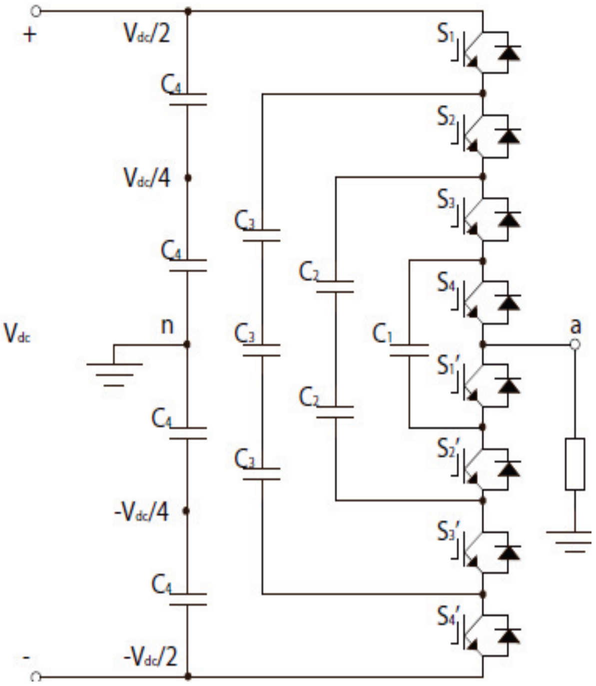

Fig.19: Single phase 5 level flying FC MLI

4.2 Flying capacitor MLI

This structure is similar to diode clamped MLI but the differentiation is the clamping diodes are replaced with the capacitors as shown in Fig.19. It has three DC side capacitors with different voltages. For inverter with m levels it needs 2 (n-1) switches, (n-1) voltage sources and ((n-1) (n-2))/ 2 clamping diodes. In reference [41] the soft switching Flying capacitor MLI is discussed, it can be extendable to any level, the advantage of this circuit is, it has very low voltage stress on the switches due to the use of coupled inductor. The snubber circuit used flying capacitor MLI improves efficiency, and reduces the switching losses [42].

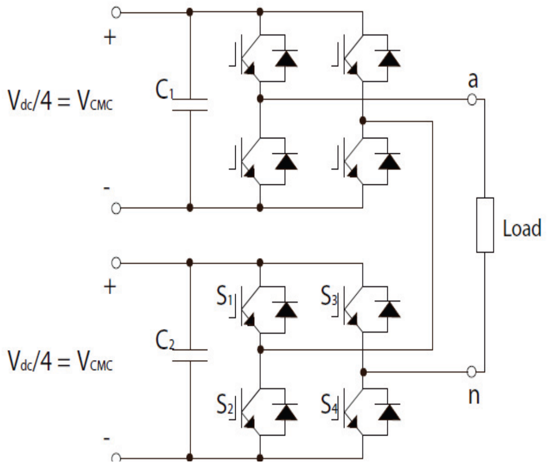

Fig.20: Single phase CHB inverter

4.3 Cascaded H Bridge MLI

The cascaded H Bridge MLI utilizes greater than one DC sources as shown in Fig.20. Each cell of the inverter generates output voltage at various levels. The resultant is the sum of all voltage levels. 2n+1 is the number of levels where n is the number of sources [43]. The advantage of this converter is it uses very fewer components than other converters. In reference [44] Emitter turn off H Bridge MLI is proposed with reactive power compensation. The H bridges are added or removed based on the requirement of output voltage and power. The number of components for various types of inverters is listed in Table. I.

5. Power Quality issues

Hybrid non-conventional energy sources like solar and wind energies are combined together to the existing gird which creates some technical problems such as Power quality issues like unbalance voltages, sag and swells, outage of power, flickering, over and under voltages, Total harmonic distortion and noises [48]. Literature survey reports give power quality problems may occur at any place of the traditional existing system and few of them are listed as below:

5.1 Voltage Sag/Swells:

Voltage Sags or dips which introduce a reduction in voltages which may last for about a second or tens of milliseconds to hundreds of milliseconds. Generally, they are produced due to many reasons like sudden increases in loads such as short circuits or faults, turning on heaters, starting of motors etc. which may cause the sudden rise of voltage over the same period for example low voltage termed as "under voltage" likewise high voltage as "over voltage". Voltage swell is generally occurring due to sudden change in the reduction of load on a circuit with poor voltage regulation and may be caused by loose neutral connection [49] [70]

Table. I: Comparison of components in MLI

Type of MLI	% THD	Level	Capacitor	Diode	Transistor	DC Source
CHB [45]	High	5	2	12	12	2
NPC [46]	Low	5	4	8	6	1
FC [47]	Low	5	10	8	8	1

5.2 Voltage regulation:

Voltage magnitudes and frequencies are generally controlled by droop characteristics in DFIGs. This can be achieved by designing a voltage sensitivity analysis at PCC. In order to produce the best AC power quality, a high DC bus ripple is used for voltage-driven and results in bidirectional power flow with decentralized control methods which makes DG systems well organized and controlled.

5.3 Total Harmonic Distortions:

During the past two decades, a modern power generation from wind energy is being focused as they are considered as potential sources to generate electricity which is clean and pollution-free. A wind turbine is a reason for bad power quality which is generally caused due to variable speed wind turbines since they need to force commutated inverters which generally produces harmonics [49]. One of the major effects of the power system is harmonics which increase the current or voltage in the system to its fundamental frequency which causes harmonic distortion in the voltage waveform and creates distortion in the whole system which may lead to many problems.

6. Control methods

There are various parameters to inspect and think about various control frameworks dependent on which control framework is thought about. Few parameters utilized for these examinations are clarified as pursues are the controller design, operation channel of the inverter, modulation methods and essential features. Note that the controllers will be arranged and completely clarified in the following area [46]. Fig. 21 shows the essential features which show a detailed layout for appropriated distribution networks. Contingent upon the association of the age framework either to the benefits system else to neighborhood stacks, the power produced can be transmitted to one of the systems. In the power transformation unit, a one-stage inverter with an inductor filter acts as an interlink between the power-producing framework or nearby loads as appeared.

1) Input-side controller: This controller is utilized in order to extract maximum power from the input source and also protects the converters at input side.
2) Grid-side controller: The following are tasks performed by this controller:

- Active Power delivered to the Grid
- Reactive Power exchange in between the Grid and DG
- DC-Link Voltage
- Power quality and Grid Integration

The converter should have the fundamental highlights recorded previously. Moreover, the network administrator may ask for subordinate administrations like voltage regulation, filtering, and harmonic elimination.

6.1. Execution platform:

Analog and Digital are two frameworks where all the control systems can be designed and implemented which are listed below with their merits and demerits

6.1.1. Analog Controllers

Control systems whose excitation and response are designed and implemented with the help of S domain transformation or time-continuous analyses. Merits of this system are continuous processing, high dynamic range, robust against crash and so on and the drawbacks are interference, complex to build in comparative logic, slow in-process and difficult in executing MIMO.

6.1.2. Digital Controllers

Control Systems whose inputs are digital and the outputs are implemented and designed with the help of time-discrete analysis or Z transformation. Merits of these systems are easy to build to do MIMO which is the main drawback that occurred in an Analog system, flexibility, fast development, easy to construct a comparative logic, robustness against interferences. The drawbacks of this system arise processing speed is the less, less dynamic range [46]. The technologies used in designing the control systems in the digital system are categorized and listed below:

- Digital Signal Processor
- Field Programmable Gate Array
- Microcontroller

Most of the usage's incredible scientific articles are DSB based implementation. Data is processed using fixed-point arithmetic with the help of powerful versions which used floating-point. FPGAs can be used for some fast controllers as they have the merits of modifying the program in the framework to decide bugs and parallel structures. The microcontroller is a traditional processor employed for slow processing applications.

6.2. Reference frame

1-Φ or 3-Φ systems in the grid integrated systems which is suitable with the power system can be implemented by control systems design for the conversion of 1-Φ and 3-Φ systems into different systems are considered as following [50]

6.2.1. abc reference frame

Three-Phase systems are framed in such a way that in each phase current an individual controller has to be used. For the design of three-phase system star or delta connection is considered. In order to deliver quick dynamic response, non-linear controllers are utilized.

6.2.2. Synchronous reference frame

However, three-phase systems are transformed to a dq frame to generate a reference frame that is obtained from grid current and voltage waveforms after transformation which rotates at the same time with the voltage at the grid. In this process, constant variables vary into DC variables which are simply removed and controlled as shown in Fig.22 the architecture of the synchronous reference frame [51-52].

6.2.3. Clark Transformation frame

To obtain αβ-frame (CT) used to change a three-phase or single phase frame. A reference frame called the stationary reference frame with the help of a grid current [53]. During this process, constant variables are converted into sinusoidal quantities as shown in Fig. 23 which is the general architecture of the stationary reference frame controller.

6.3. Various types of output filter of inverter

The current harmonics which are generated by switching action of semiconductor devices are reduced with these filters. L or LC, LCL filters are utilized to connect the output of the inverter [54] (Fig. 24).

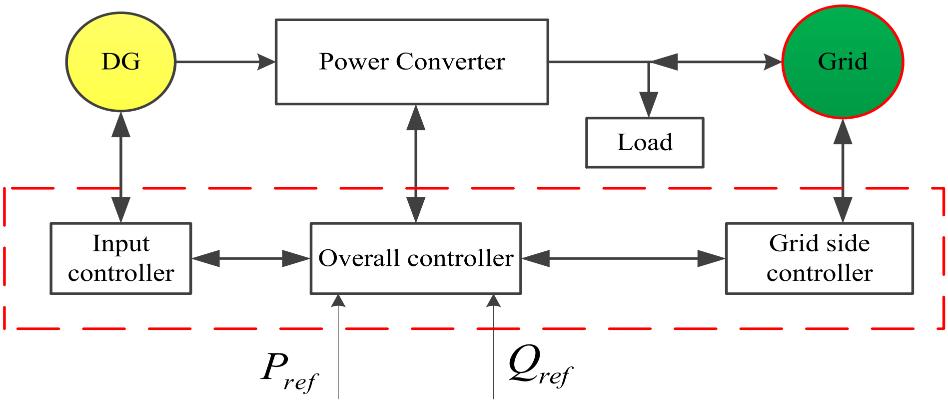

Fig.21: The general structure of DG integrated grid with the controller

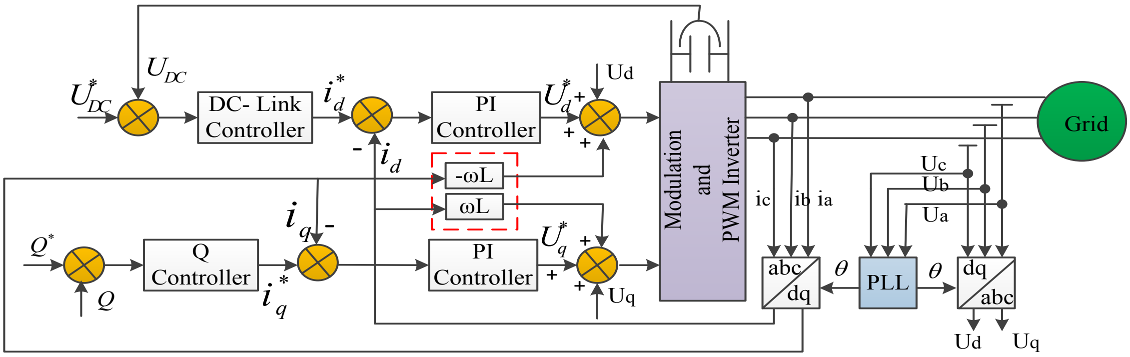

Fig.22: Synchronous rotating reference frame controller

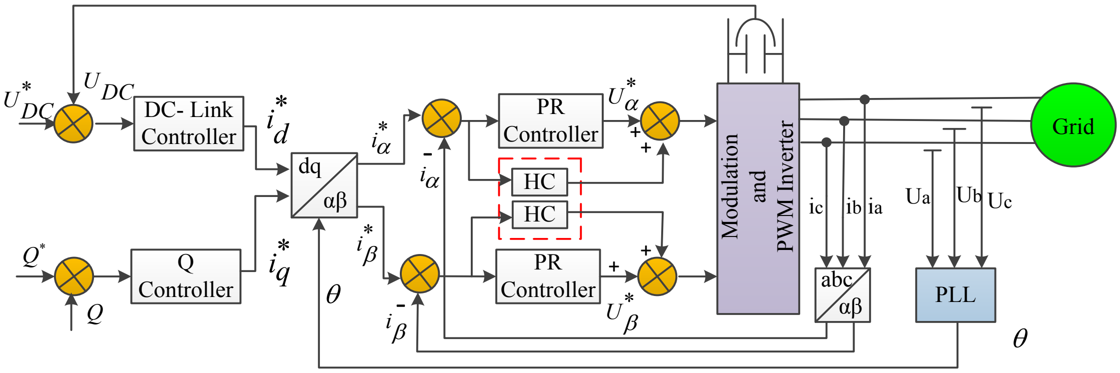

Fig.23: Stationary reference frame controller

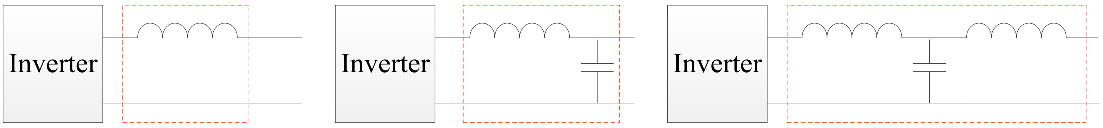

Fig.24: Various types of filters

6.3.1. L-Filter

This filter is mostly utilized for the converters having high operating frequency whose reduction of amplitude is sufficient. The advantage is that inductance reduces the dynamics of the converter filter system. This filter is called the first-order filter.

6.3.2. LC-Filter

It is simple and easy to design which often creates no problems during its functioning. The design of such a filter mainly depends on the values of both capacitance and inductance. The higher the value of capacitance would have a good effect on the voltage quality. Higher the values of inductance for achievement demanded cut-off frequencies. The filter whose resonant frequency is depended on the grid impedance when the system is connected to the supply grid. This filter is called a second-order filter

6.3.3. Filter

With the help, this filter lower operating frequencies required by the inverter can be used since there exist better unconnected across grid impedance and the filter. Since the values of inductances of this filter are smaller and have better current ripple attenuation. Moreover, this filter brings unstable states and resonance into the system. Therefore, these filters are carefully designed by considering various parameters required.

6.4. Control strategy

In contrast, to produce the high quality of the power there should be some control techniques to be implemented. Likewise, unbalance current, harmonics, reactive power at PCC are reduced by developing control strategies. The final results achieved by implementing various optimization techniques system results in effectiveness for eliminating the PQ problems such as THD. Control system planned and executed as a feedback system categorized as below [55]

6.4.1. Single-loop control system

In this framework, just one value is controlled which makes the basic and economical structure, yet performance in the poor task.

6.4.2. Multi-loop control systems

Here two feedback loops are used such as one is innermost and the other outermost feedback loops. Various closed paths considered in the architecture of these controllers as shown in Fig.25 which is an example of having both innermost and outermost loop. The bandwidth of the inner loop is wider compared to the outer loop and results in the improvement of the dynamic performance of the systems. The control structure design is complex but it is expensive because of the usage of many sensors.

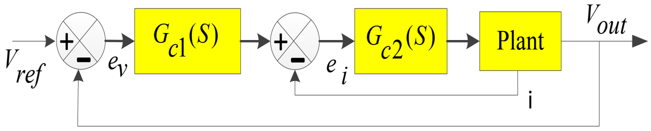

Fig.25: Multiple loop controller structure

7. Controllers for Power Quality Improvement

The design of the controller is most important as the distributed network is connected to the grid which results in many problems like disturbance and instability. In this paper, few controllers are introduced according to their applications [56].

7.1. Linear controllers

These controllers have the properties of the linear networks. They are designed with the use of traditional feedback controllers.

7.1.1. Classic controllers

P, PI, and PID controllers which are called basic controllers used in linear systems in the classic controller are utilized [57].

7.1.2. Proportional Resonant controllers

PR and PI controllers are very commonly used controllers. The deviation between both of them is the manner in which the combining takes place. Integrator coordinates frequencies that are exceptionally near the resonance frequency in a PR controller. Static error is excluded

7.1.3. Linear Quadratic Gaussian controllers

This controller is associated along with a linear quadratic regulator with kalman filter. The partition guarantees that they are processed and structured autonomously as shown in Fig. 26 LQG control which includes linear time-changing frameworks and LTI systems [58]. Hence utilization of LQG control to LTV frameworks gives the structure of straight criticism controllers for nonlinear unsure systems.

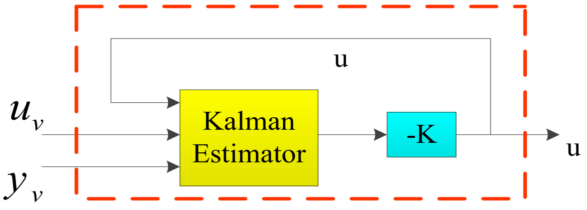

Fig.26: LQG controller structure

7.2. Nonlinear controllers

They have a phenomenal task contrasted to essential controllers, yet they are so convoluted as far as execution and plan.

7.2.1. Sliding mode controllers

Inverters have been introduced with SMC procedure for the control of output voltage. The main advantage is that it is less affected by the load interruption and value variations. In this manner, the Constant steady-state response can be accomplished in the practical case. Apart from this, it is difficult to handle an appropriate sliding surface. SMC can be degraded with a restricted sampling rate. The demerit of SMC is chattering when following a variable reference. In this way, it will corrupt the overall system effectiveness [59].

7.2.2. PFL controllers

Feedback linearization is the design of nonlinear controllers since it changes a nonlinear framework to a partially linear or a completely linear framework. It is accomplished by eliminating the nonlinearities inside the framework [60]. In this manner, linear controller plan strategies can be utilized to develop the controller for these frameworks. It is called as FFL when the nonlinear framework is changed to a complete linear framework if not it is called partially feedback linearization (PFL). At the point when the nonlinear framework is changed into a complete linear framework, the technique is named the FFL and if the nonlinear framework is changed into a PFL, the strategy is called partially feedback linearization.

7.2.3. Hysteresis controllers

In order to design the hysteresis and an adaptive band of the controller should be developed to accomplish a suitable operating frequency. Moreover, to take into account with respect of the isolated neutral is main as the response is the state switches [61].

7.3. Robust controllers

This controller is a power controller that is designed to approach with respect to the uncertainties. Its main aim is to accomplish strong execution with limited errors. In these controller good principles, detailed specifications and limits should be defined. Robust stability and properties of the closed-loop system can be achieved in the multivariable system [62].

7.3.1. H-interminability controllers

For the implementation of the H-∞ approach, the designed architect depicts the control problem as a development problem and executes. Even in multivariable system problems, this H-∞ can be applied. This method is having high calculation speed and requires the best structure of the systems to be controlled. Nonlinearity is basically not well-considered [63].

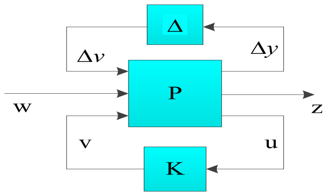

Fig.27: Robust controller

7.3.2. Mu-Synthesis controllers

This method utilized to overcome the impact of the pattern and unpatented disturbances on the conduct of the model [64]. The architecture of the controller is depended on the conception of constructed singular value Fig. 27 gives the basic structure.

7.4. Adaptive controllers

These strategies would naturally modify the control activity relying upon the working states of the framework. In fact, there is no compelling reason to know the precise framework values with the elite. All things being equal, the calculation intricacy conspire is high. In [65], control is utilized. Fig. 28 demonstrates the control framework for this control.

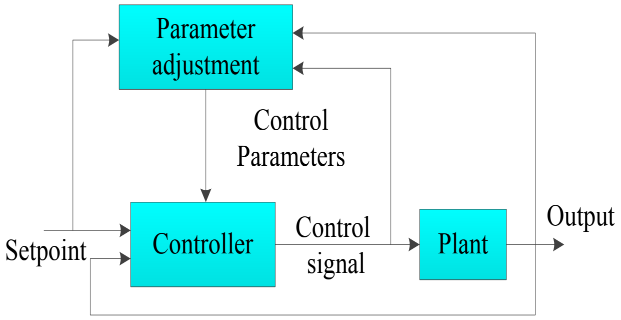

Fig.28: Adaptive controller

7.5. Predictive controllers

Prescient controllers utilize a framework design to anticipate the forthcoming conduct of controlled values. It utilizes the data to get the ideal activation, contingent upon a predefined enhancement standard. With its extremely quick unique reaction, nonlinearities, and imperatives which are effectively included it tends to be connected to different frameworks while a multivariable case can be considered; moreover, the usage is simple [66]. Contrasted with an exemplary controller, the anticipating controller needs an incredible number of estimations as shown in Fig. 29.

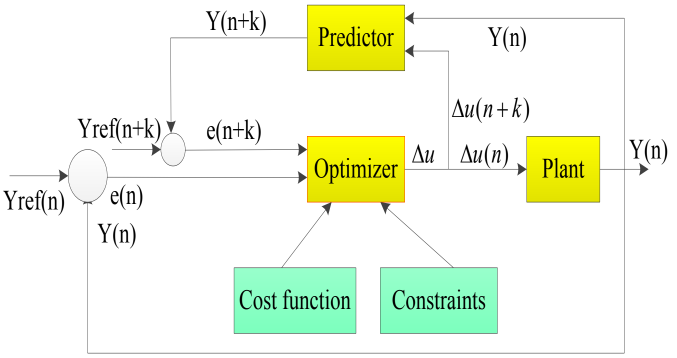

Fig.29: Model predictive controller

7.6. Repetitive controllers (RC)

The essential thought of such a controller originates from the interior structure rule. In case the system of any reference is involved in the feedback path then better collection can be obtained. The simple design of RC controllers is shown in Fig. 30. Q (z-1) and S (z-1) give C(S)/R(S) of the controller and the number of samples as N [67].

Table-III: Sensitivity analysis of various controllers

Controller	**Reference frame**	**Feed back**	**Modulation**	**Filter**	**Control parameter**	**Application**	**Complexities**	**Sensitivity**	**Efficiency**	**Stability**	**Speed of convergence**	**Hardware implementation**
Adaptive	Three- Phase, dq	Multiple-loop	PWM	LC	Power	DG	High	Low	High	Low	High	Yes
Repetitive	Single-Phase	Single-Loop	SPWM	L	Current	General	Low	Low	Medium	High	Low	Yes
PR	Single-Phase	Single-Loop	PWM	LCL	Current	PV	Low	Low	High	Low	High	Yes
PR	Three phase, αβ	Single-Loop	SVM	LCL	Current	PV	High	Low	High	High	High	Yes
LQG	abc, dq	Single-Loop	PWM	LCL	Current	General	High	Low	High	High	Medium	Yes
LQG	abc, αβ	Single-Loop	SVPWM	L	Current	PV	High	Low	Medium	Medium	Low	Yes
RC	Single-Phase	Single-Loop	PWM	LCL	Current	General	Low	Medium	Medium	High	Low	Yes
Hysteresis	Single-phase	Multiple-Loop	PWM	L	Current	General	High	Low	Low	High	Low	Yes
Hysteresis	Three phase, αβ	Single-Loop	PWM	LCL	Current	General	Low	High	High	Low	High	Yes
MPC	Three-Phase, abc	Single-Loop	PWM	LCL,LC	Voltage, Power	DG	High	Low	Medium	High	Medium	Yes
MPC	Three phase ,αβ	Single-Loop	PWM	L	Current	General	Low	High	High	Low	High	Yes
MPC	Three- Phase, dq	Single-Loop	SVPWM	L	Current	General	High	Low	High	Low	Medium	Yes
H∞	Three- Phase, dq	Single-Loop	PWM	LC	Current	General	Low	High	Low	High	Low	Yes
H∞	Three phase, αβ	Multiple-Loop	PWM	LC	Current	General	High	Low	High	Low	High	Yes
Fuzzy, NN	Three-Phase, abc	Multiple-Loop	PWM	L	Power	PV	High	Low	High	Medium	Low	Yes
Classic, NN	Three-Phase, abc	Multiple-Loop	PWM	L	Power	PV	High	High	Medium	Low	High	Yes
SMC, Fuzzy	Single-phase	Multiple-Loop	PWM	LC	Voltage	UPS	Low	Medium	Medium	High	High	Yes
SMC	Three- Phase, dq	Single-Loop	PWM	L	Current	PV	High	High	Low	Medium	Low	Yes

RC has no necessary dynamic response in spite of its appropriate characteristics produced with timely nonlinear loads. On the other hand, the series structure is used to resolve these issues RC is combined with favourable dynamic response controllers.

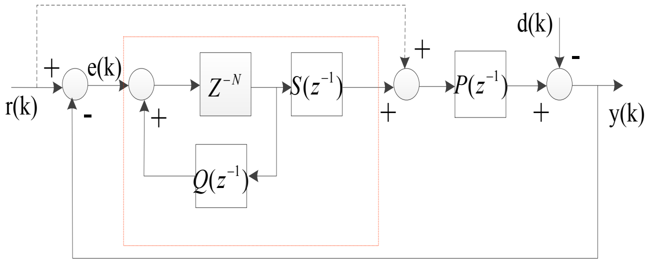

Fig.30: Repetitive controller

7.7 Neural Network controllers

The neural system is an association of various artificial neurons, which mimic a natural mind framework. It can gauge a discretionary capacity mapping and can acquire a higher adaptation to non-critical failure. In framework control NN can prepare on-line or off-line when used. NN can prepare on-line or off-line when it is utilized in a framework control [68].

7.8 Fuzzy logic controllers

Fuzzy control is a technique to characterize and actualize the learning of a brilliant human to operate a framework. Fig. 31 outlines the model accompanying the segments [69]

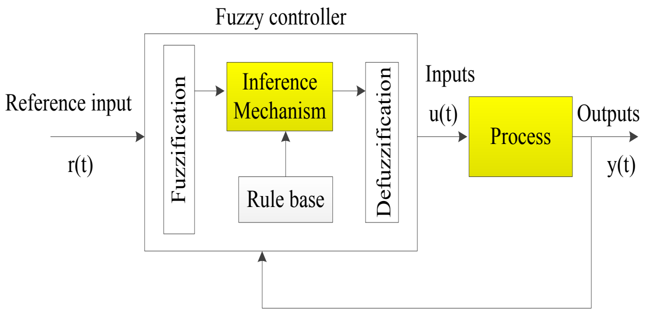

Fig.31: Fuzzy controller

- The step- base is an accumulation of guidelines about how to operate and control.
- Fuzzification is the way toward changing over the numerical contributions to a structure utilized by the inference component.
- The inference mechanism utilizes data with respect to the information sources shaped by fuzzification and chooses what steps to be applied to the present status; it additionally relies upon plant and structures conclusions.
- Defuzzification changes the outputs accomplished by the interconnected system to neumerical numerical contribution for the plant.

The following are the merits and demerits of the various controllers used by various researchers in designing are listed in Table.2 The sensitivity analysis of various controllers is listed in Table.III.

Table. 2: Merits and demerits of Control Methods

Type	Control strategies	Merits	Demerits
Linear controllers	PI Controller	• Easy to achieve desired value accurately • Easy to apply for fast response process	Can't be used for Slow-moving process variables
	Proportional Resonant controllers	• At fundamental frequency, they introduce infinite gain • Zero steady-state errors can be achieved	Only at controller resonant frequency, Error-free performances are obtained
Non linear controllers	Sliding mode controllers	• Strong from uncertainties and disturbances • Maintains stability	Complex in implementation
	PFL controllers	• Fast operation • Integrated and complex systems need simple mathematics	• Fuzzy grades required are more for better accuracy • Real-time response is lacking
	Hysteresis controllers	• Design is simple • Strong in nature • Very good dynamics are provided	• Fixed frequency switching is not present • Switching losses are very high and applied to low power levels. • Load parameter variations lead to resonance problems

	Robust controllers	• In the process of set-point tracking, it has the capability to cancel both measured and unmeasured disturbances	Not suitable for weather change conditions
	H- Infinity controllers	• Low THD. and improves PQ • Good performance is ensured at all conditions	• Modeling is complex and requires good expert Dynamics are less
	Repetitive controllers	• Eliminates periodic disturbances • At all harmonics frequency, zero steady-state error is ensured	• Load fluctuations arise slow responses • When load disturbances are a periodic then there would be a stability problem
	Neural network controllers	• Strong in nature and used in the current controller	The drawback of performance in the off-line training method.
	Fuzzy logic controllers	• Encourages to system variations • Heuristics and expert knowledge takes over the advantage to manage the nonlinear behavior of complex control structure	• Difficulty in the practical implementation

8. Conclusion

This paper presents various advanced DC converters, inverters, and controllers for hybrid grid integration using renewable energy sources and their applications. They were explained briefly and examined with the most important features. The advanced CHB inverters have been providing efficient output for renewable energy source applications with a good control strategy. The reviews of controllers indicate choosing a better controller will give good efficiency. Depending upon the expected tasks and system conditions of the control system, parameters should be the primary concern. The complete review of different systems along with comparison and application of each system proposed in the paper is very useful to the researchers while selecting good DC converters, inverters and controllers for hybrid grid applications

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