CHAPTER 1

INTRODUCTION

1.1 RENEWABLE ENERGY SOURCES

World final energy consumption is less than the total primary energy supply due to the energy lost in conversion process and its transmission process. In energy conversion, renewable sources replace the conventional fuels due to the advancements in technology and also with mass production. Among the Renewable Energy Sources (RES), solar and wind energy are reliable, environmental pollution free and efficient sources. Wind powered generators can be used as standalone systems or combined with solar panels and/or hydro power. A standalone power system is an off-the-grid electricity system for locations that are not equipped with an electricity distribution system.

Wind Energy Conversion Systems (WECS) can be connected to the electricity distribution system and are termed as grid connected systems. The basic model of a direct coupled solar system consists of a solar panel connected directly to a DC load. In standalone Photo Voltaic (PV) power systems, the electrical energy produced by the PV panels cannot always be used directly. As the demand from the load does not always equal the solar panel capacity, battery banks are generally used. A grid connected PV power system is an electric power generating solar PV system that is connected to the utility grid. Solar energy gathered by PV solar panels, intended for delivery to a power grid, must be conditioned or processed by a grid connected inverter and also has to synchronize the AC output with the AC supply in the grid.
The hybrid power plant is a complete electrical power supply system that can be easily configured to meet a broad range of remote power needs. Sources for hybrid power include wind turbines, diesel engine generator sets and solar PV systems. A hybrid energy system consists of two or more renewable energy sources used together to provide increased system efficiency as well as greater balance in energy supply. Research and Development efforts in solar, wind and other renewable energy technologies are on improving their performance, establishing techniques for accurately predicting their output and reliably integrating them with other conventional generating sources.

Instead of connecting the renewable energy sources directly to load or grid, intermediate conversion devices are used to improve their performance.

1.2 CONVERTERS FOR INTERCONNECTION OF POWER SYSTEM BASED RES

Converter is a device used for interconnection of renewable energy sources with power system to convert one form of fixed input into same or another form of variable output. Demands for lower cost, smaller size and higher efficiency will continue to further expand the range of converter applications.

To interconnect solar system, different inverter configurations exist which has their own characteristic features and efficiency. Since a three-phase bridge inverter provides adjustable frequency power than any other type of inverters, it is preferred for industrial applications. In power electronics, various Pulse Width Modulation (PWM) techniques are widely employed to control the output of inverters. Three phase voltage fed PWM inverters are
recently showing growing popularity for multi megawatt industrial applications. The main reasons for this popularity are easy sharing of large voltage between the series devices and the improvement of the harmonic quality at the output compared to a two level inverter.

One important method is SPWM control. The pulse widths are generated by comparing a triangular reference voltage $v_r$ of amplitude $A_r$ and frequency $f_r$, with a carrier half sinusoidal voltage $v_c$ of variable amplitude $A_c$ and frequency $2f_s$. The sinusoidal voltage $v_c$ is in phase with the input phase voltage $v_s$ and has twice the supply frequency $f_s$. The widths of the pulses (and the output voltage) are varied by changing the amplitude $A_r$ or the modulation index from 0 to 1. The modulation index is $A_c/A_r$. It is noted that the width of the pulses obtained are variable.

Based on the PWM methods applied, the harmonic component of the voltage waveforms also gets varied. Output of voltage source inverters is corrupted by significant amount with many low order harmonics 3rd, 5th, 7th, 11th, 13th order of the desired (fundamental) frequency. Inverters used for ac motor drive applications are expected to have less amount of lower order harmonics in the output voltage waveform, even if it is at the cost of increased higher order harmonics. Higher order harmonic voltage distortions in most ac motor loads are filtered away by the inductive nature of the load itself.

AC to AC converter is a device which can convert fixed AC to variable AC (with variable voltage and frequency). It is used to interconnect wind energy conversion system to power system. AC to AC voltage converters operates on the AC mains essentially to regulate the output voltage. Several topologies have emerged along with voltage regulation methods, most of which are linked to the development of the semiconductor
devices. Various types of converters which are used to convert AC input into AC output are listed below,

- Conventional AC-DC-AC (Indirect AC-AC) converters
- Matrix (Direct AC-AC) converters

The AC-DC-AC converter topology is the only available converter industrially, which is used in the application of driving AC motors. This topology is constituted of a rectifier stage and an inverter stage. The rectifier stage contains energy storage elements, such as a bank of capacitor, which are required to provide the constant voltage (DC-link) to the inverter stage. The DC-link of the converter is bulky and costly. The inverter stage is relatively smaller than the corresponding rectifier stage, but acquires a snubber network circuit that is no longer needed in modern converters. In general, the topology can be described as:

1. Consisting of switching devices and energy storage (reactive) elements that cause the converter to be large sized and costly.

2. It is unable to regenerate energy back to the main supply source.

Either the Space Vector Modulation (SVM) technique or the carrier based PWM technique could be used to control the switching of the converter. A block diagram of the conventional inverter based AC-DC-AC converter topology is shown in Figure 1.1.
In conventional AC-DC-AC converter sinusoidal pulse width modulation technique is used to produce gate pulses for the inverter switches. The voltage source inverter that use PWM switching technique, have a DC input voltage that is usually constant in magnitude. The inverter considers this DC input and generates AC output, where the magnitude and frequency can be controlled. There are several techniques of PWM. The efficiency parameters of an inverter such as switching losses and harmonic reduction are principally depended on the modulation strategies used to control the inverter. In this, design technique has been used for controlling the inverter as it can be directly control the inverter output voltage and output frequency according to the sine functions.

The switching signal is generated by comparing the sinusoidal waves with the triangular wave. The comparator gives out a pulse when sine voltage is greater than the triangular voltage and this pulse is used to trigger the respective inverter switches. In order to avoid undefined switching states and undefined AC output line voltages in the Voltage Source Inverter (VSI),

![AC-DC-AC converter diagram](image_url)
the switches of any leg in the inverter cannot be switched off simultaneously. The phase outputs are mutually phase shifted by 120°.

A Matrix Converter (MC) is a device which gives single stage conversion used for converting directly AC energy into AC energy without any intermediate dc link. The main feature of this device is to convert the magnitude as well as the frequency of the output into a desired magnitude and frequency. MC consists of nine bi-directional switches arranged in an array manner which are required to be commutated in the suitable manner and sequence in order to minimize losses and produce the desired output with a high quality input and output waveforms.

The main advantage of MC is the absence of bulky reactive elements that are subjected to ageing and reduces the system reliability. Furthermore, MCs provide bidirectional power flow, nearly sinusoidal input and output waveforms with controllable input power factor. Therefore MCs have received considerable attention as a good alternative to VSI topology.

From the above discussions, PWM method is preferred for solar PV system and MC is preferred for wind energy system connected load or grid.

1.3 SELECTIVE HARMONIC ELIMINATION PWM (SHEPWM) INVERTER

Sinusoidal Pulse Width Modulation, the Space Vector technique and the Selective Harmonic Elimination (SHE) technique are the carrier based modulation technique mostly used.

Increasing the switching frequency (rate at which device switch on and off) in sinusoidal-triangular PWM and SVPWM for two level inverters or
adopting phase shift in multicarrier based PWM are some of the methods to improve the performance. For medium and high voltage / power applications, the SPWM and the number of switching angles are limited by switching loss and are used when the available voltage steps are limited. In SHEPWM the number of eliminated harmonics is decided by the number of switching angles in voltage waveform. There can be multiple solutions for output voltage waveforms. SHE technique provides several advantages compared to traditional modulation methods, which are acceptable performance with low switching frequency to fundamental frequency ratios and direct control over output waveform harmonics.

SHEPWM technique is an effective technique for the elimination of lower order harmonics in two and three level inverters. SHE is a well-known technique for generating PWM signals that can eliminate specific lower order harmonics from a voltage waveform generated by a VSI. The SHEPWM method is mathematically formulated by Fourier analysis of waveform. The SHEPWM technique is used to analyse the output voltage waveform of a three level inverter. Conventionally Newton-Raphson method is used to solve the SHE problem. This method is derivative-dependent, time consuming and involves more mathematical calculations. In order to reduce the computational burden and time, Artificial Intelligent technique such as Genetic Algorithm (GA) is used to solve the objective function of SHE problem.

Due to the effectiveness of SHEPWM inverter, it is used to connect solar PV system to grid.
1.4 MATRIX CONVERTER

The MC is more reliable and is smaller because the bulky dc capacitor is eliminated from the topology. Therefore, when MCs are used in ac–ac power conversion, the size and weight of the whole system is reduced. The MC consists of 9 bi-directional switches that allow any output phase to be connected to any input phase. The input terminals of the converter are connected to a three phase voltage fed system, usually the grid, while the output terminals are connected to a three phase current fed system. The capacitive filter on the voltage fed side and the inductive filter on the current fed side are represented in the scheme. Their size is inversely proportional to the MC switching frequency. It is good due to its inherent bi-directionality and symmetry, a dual connection is also feasible for the MC, a current fed system at the input and a voltage fed system at the output.

With nine bi-directional switches the matrix converter can theoretically assume 512 different switching states combinations. But not all of them can be usefully employed. Regardless of the control method used, the choice of the matrix converter switching state combinations to be used must comply with two basic rules. Taking into account that the converter is supplied by a voltage source and usually feeds an inductive load, the input phases should never be short circuited and the output currents should not be interrupted. From practical point of view these rules imply that one and only one bi-directional switch per output phase must be switched on at any instant. By this constraint, in a three phase to three phase matrix converter 27 are the permitted switching combinations.

Due to reliability and size of the MC, it is selected to connect wind energy system to grid.
1.5 HARMONIC DISTORTIONS

The improvement of power quality has been the major issue in power electronics system. The elimination of specific lower order harmonics improves the performance of system. The main advantage of using power electronic equipment result in higher performance and lower power energy consumption but almost all power electronic equipment behave as nonlinear loads. Therefore harmonics are injected into the system. Harmonic distortion of current occurs when sinusoidal voltage is applied to a non-linear load. This results in distortion of the fundamental current waveform. This distortion occurs in integer multiples of the fundamental frequency. Also voltage distortion is generated indirectly as a result of harmonic currents flowing through a distribution system.

It is important to note that the vast majority of harmonic currents found in a distribution system are odd-order harmonics (3\textsuperscript{rd}, 5\textsuperscript{th}, 7\textsuperscript{th}, etc.). The triple harmonics are defined as the odd multiples of the 3\textsuperscript{rd} harmonic. Triple harmonics are of particular concern because they are zero sequence harmonics, unlike the fundamental, which is positive sequence. The consequence of this fact is that the magnitude of these currents on the 3 phases are additive in the neutral. This can lead to very large currents circulating in the neutral. These currents can also circulate in the transformer causing significant overheating. Single phase power supplies for equipment such as electronic ballasts and personal computers are the most significant source of triple harmonics. The 5\textsuperscript{th} and 11\textsuperscript{th} harmonics are also of particular concern in industry today. Although the 5\textsuperscript{th} harmonic is much more prevalent, both have a negative sequence. This means that when distorted voltage containing the 5\textsuperscript{th} or 11\textsuperscript{th} harmonic is applied to a 3 phase motor, it will attempt to drive the motor in reverse, creating a negative torque. In order to compensate for this negative torque, the motor must draw additional
fundamental current. This in turn, can cause overheating or the tripping of over current protection devices. Six pulse adjustable speed drives are a major source of the 5th, 7th and 11th harmonics. Twelve pulse drives are significantly more expensive and are a source of the 11th and 13th harmonics but through their design they are able to eliminate the 5th and 7th harmonics. The 7th harmonics causes destructive heating and derating of devices such as transformer and capacitor banking. And also improper operation of voltage balance relay may occur.

In general, harmonics present on a distribution system can have overheating of transformers and rotating equipment, increased hysteresis losses, decreased kVA capacity, neutral overloading, unacceptable neutral-to-ground voltages, distorted voltage and current waveforms, failed capacitor banks, breakers and fuses tripping, interference on phone and communications systems, unreliable operation of electronic equipment, erroneous register of electric meters, wasted energy/high electric bills, wasted capacity inefficient distribution of power and increased maintenance of equipment and machinery.

Many electronic controllers detect the point at which the supply voltage crosses zero to determine when loads should be turned on. This is done because switching reactive loads at zero voltage does not generate transients, thus reducing electromagnetic interference and stress on the semiconductor switching devices. When harmonics or transients are present on the supply the rate of change of voltage at the crossing becomes faster and more difficult to identify, leading to erratic operation. In order to reduce the above problems, the selective harmonic elimination technique is employed based on applications.
1.6 OPTIMIZATION ALGORITHM

Optimization is a process that finds the best solution for a problem. GA represents an intelligent exploitation of a random search used to solve optimization problems. In nature, competition among individuals for scanty resources results in the fittest individuals dominating over the weaker ones. Some of the advantage of GA is that it is better than conventional artificial Intelligence and it is robust. Unlike other systems, GA does not break easily even if the inputs are changed slightly or in the presence of reasonable noise. In performing search in large state space or multi model state space or n dimensional surface, GA offer significant benefits over many other typical search optimization techniques like Linear Programming, Heuristic, Depth First, Breath First search. In the field of artificial intelligence, GA is a heuristic search that minimizes the process of natural evolution. This heuristic is routinely used to generate useful solutions to optimize and search problems. GA belong to the larger class of Evolutionary Algorithms, which find solutions to optimization problems using techniques inspired by natural evolution, such as inheritance, mutation, selection, and crossover. The important factor for optimization is an objective function which has to be maximized or minimized.

Steps involved in GA are as follows.

a) Initial Generation

In Genetic Algorithm, a population of strings (called chromosomes or the genotype of the genome), which encode solutions (called individuals, creatures or phenotypes) to an optimization problem, is evolved toward better solutions. Traditionally, solutions are represented in binary as strings of 0’s and 1’s, but other encodings are also possible. The evolution usually starts from a population of randomly generated individuals and happens in
generations. This random generation population is close to our objective function. The range for creating population is also specified. So the random generation selects the values close to the fitness value.

**b) Performance Evaluation**

The performance is evaluated based on the objective function. The objective function is to maximize the output voltage of the inverter and minimize the harmonic content.

**c) Fitness Calculation**

A standard representation of the solution is as an array of bits. The main property that makes these genetic representations convenient is that their parts are easily aligned due to their fixed size, which facilitates simple crossover operations. The fitness function is defined over the genetic representation and measures the quality of the represented solution. The fitness function is always problem dependent. For the proposed system objective function is a minimization function. A representation of a solution might be an array of bits, where each bit represents a different object.

**d) Selection**

During each successive generation, a proportion of the existing population is selected to breed a new generation. Individual solutions are selected through a fitness based process, where the best solutions are measured by fitness function. Certain selection methods rate the fitness of each solution and preferentially select the best solutions. Other methods rate only a random sample of the population, as the former process may be very time consuming.
e) Recombination (Cross Over)

The next step is to generate a second generation population of solutions from those selected through genetic operators. For each new solution to be produced, a pair of "parent" solutions is selected for breeding from the pool selected previously. By producing a "child" using methods of crossover, a new solution is created which typically shares many of the characteristics of its "parents". New parents are selected for each new child, and the process continues until a new population of solutions of appropriate size is generated. Although reproduction methods that are based on the use of two parents are more biology inspired, these processes ultimately result in the next generation population of chromosomes that is different from the initial generation. Generally the average fitness will increase by this procedure for the population, only the best organisms from the first generation are selected for breeding, along with a small proportion of less fit solutions. For example consider the following parent

Parent 1: 0010 1101 Parent 2: 0101 1011

Child 1: 0010 1011 Child 2: 0101 1101

f) Mutation

The mutation is the process of changing the bits in the population. The sudden change produces the individuals that converge to the best result. The cross over produces the new off spring and the mutation changes the bits by some techniques for example, roulette wheel selection method.

Roulette Wheel is used to replace the worst fitted data. The general process is to replace the worst fitted value by the best fitted value. Sometimes mean fitness value is used and data with fitness values below 50% of the
mean fitness value are replaced by the best fitted data. If the best fitted value of the table of values achieved by this process is closer to the criteria given by the user, then the older table is replaced by this new table.

g) Reinsertion

In this process, the newly selected populations are inserted into the initial process. Then the process continues for each generation. The number of population and the range of population can be specified. One can see that Genetic Algorithm repeatedly modifies a population of individual solutions. At each step, selects individuals at random from the current population to be parents and uses them to produce the children for the next generation. Over successive generations, the population "evolves" towards an optimal solution.

1.7 LITERATURE SURVEY

The aim of this research work is to identify converters for grid connected PV systems, WECS and Hybrid system. So Literature survey has been done in the area of SHEPWM inverter, Grid Connected Inverters, Matrix Converter, Wind Energy Conversion System (WECS) based MC and Hybrid Systems.

1.7.1 SHEPWM Inverter

Chiasson et al. (2004) converted the transcendental equations that specify the harmonic elimination problem an equivalent set of polynomial equations. The complete solutions for both unipolar and bipolar switching patterns to eliminate only the $5^{th}$ and $7^{th}$ harmonics are discussed. The maximum voltage Total Harmonic Distortion (THD) generated using above elimination theory is 43.3% and current THD of 17.6%.
Jason et al. (2005) proposed a method to remove the quarter-wave symmetry constraint for two classes of the m-level, n-harmonic control problem. This problem formulation gives the designer much more flexibility in selecting the uncontrolled harmonic content. The special cases of two and three level harmonic elimination are presented in detail along with representative solutions for each harmonic control problem.

Shi & Li (2005) applied GA to optimize a PWM inverter. It is proved that the optimized PWM technique is superior to standard triangular PWM and random PWM techniques. But the improvement is not significant when the switching frequency is higher than 5 kHz.

Agelidis et al. (2006) discussed a minimization technique to solve the SHEPWM control method for inverters. The method finds the complete set of solutions of a given problem and confirms that multiple solutions exist. Results also discussed for even number of odd harmonics for a three phase system.

Jason et al. (2007) insisted on the method based on modulation rather than solution of nonlinear equations or numerical optimization. The approach is based on a modified carrier waveform. It rapidly calculates the desired switching waveforms. Calculation time is insensitive to the switching frequency ratio.

Blasko (2007) identified the function to eliminate undesirable higher harmonic components from selected variable (current or voltage) and it requires only knowledge of the frequency of the component of plant to be eliminated. Through an adaptive process it creates harmonic signal, which is injected into the system in order to cancel the harmonic component in the
control variable. The algorithm was able to efficiently eliminate only 5\textsuperscript{th} and 7\textsuperscript{th} harmonics from line current.

Sundareswaran et al. (2007) have developed a novel algorithm for SHE in a PWM inverter based on the foraging behaviour of a colony of ants. The proposed scheme has several advantages, such as computational simplicity, derivative free operation and guaranteed near-optimal convergence with random initial guess. The voltage THD that occurs using the above method is 52.2%.

Ali (2008) introduced an improved injection current technique to reduce line current harmonics. The optimal amplitude and phase angle of the injection current for different loads and firing angles have been mathematically determined. The results show a sensitive variation in the THD of the line current for the amplitude and angle of injection current variations. Optimum value and angle of injection of the third harmonic current leads the current to the sine wave with 6% THD.

Agelidis et al. (2008) discussed a direct minimization of the nonlinear transcendental trigonometric Fourier functions in combination with a random search. The multiple set of solutions are found and it is seen that not all the solutions generate the same level of the non triplen non eliminated harmonic and therefore a second level of assessment is required.

Napoles et al. (2010) proposed a special implementation of the Selective harmonic mitigation pulse width modulation technique optimized for very low switching frequency. This technique is very useful in high-power applications, leading its use to important reduction of the bulky and expensive filtering elements. Voltage THD of 34.87 % and lower order harmonics are maximum and is about 6%.
Wanmin et al. (2010) discussed Half cycle symmetry SHEPWM problems with large number of valid solutions, which are beneficial to the optimization design. The advantages of the proposed formulation include simplicity in format, flexibility in PWM waveforms and a broad solution space. SHEPWM problem for five level inverter with one value of number of odd harmonic to be eliminated is discussed.

Ahmadi et al. (2011) developed harmonics injection and equal area criteria-based four-equation method to realize optimal PWM for two level inverters and multilevel inverters with unbalanced dc sources. In medium or high power inverters, it is often used to reduce the switching frequency and at the same time, realize selective harmonic elimination.

Balasubramanian & Rajamani (2014) implemented SHEPWM using generalized Hopfield neural network to the single phase inverter. Finding the switching instants in the case of SHEPWM involves the solution of a set of nonlinear algebraic transcendental equations is redrafted as an optimization problem. This literature concentrates on the single phase inverter and first four odd harmonics elimination. Lower order harmonic content in the output is maximum and is about 9%.

From the literature survey, it is observed that most of the techniques applied to SHE problem for single phase inverters and most of the SHE problem has limited N and Modulation indices value. Different optimization techniques are also applied for SHE problem. In most of the literatures all the parameters regarding harmonics in input side and output side of inverter have not been discussed. In some papers harmonic analysis have been done with filters in the output side of the inverter.
1.7.2 Grid Connected Inverters

Kjaer et al. (2005) focussed on inverter technologies for connecting PV modules to a single-phase grid. Various inverter topologies are presented, compared and evaluated against demands, lifetime, component ratings and cost. Finally, Utility interactive PV inverter and topology of the power electronics of the three string inverter are pointed out as the best candidates for either single PV module or multiple PV module applications.

Koizumi et al. (2006) developed a novel microcontroller for grid connected PV systems. It is composed of the controller and a flyback inverter. The proposed controller is adaptable not only for a PV inverter but also for a master controller or independent equipment for grid connection.

Jain & Agarwal (2007) proposed a high performance, single-stage inverter topology based on buck boost topology for grid connected PV systems. The proposed configuration can not only boost the usually low PV array voltage, but can also convert the solar dc power into high quality ac power for feeding into the grid. THD of the current fed into the grid is 9.13%.

Franquelo et al. (2007) proposed selective harmonic mitigation PWM, which generates switching three level PWM patterns with high quality harmonic content, avoiding the elimination of some specific harmonics. The harmonics and the THD are analyzed using a general purpose random-search heuristic algorithm.

Wai & Wang (2008) addressed a grid connected PV generation system through a high step-up converter and a PWM inverter. An adaptive total sliding-mode control system is designed for the current control of the PWM inverter to maintain the output current with a higher power factor.
Moreover, the output current of the PWM inverter can almost be maintained in phase with the utility voltage.

Yazdani et al. (2009) introduced new three phase harmonic decomposition technique to extract voltage/current harmonics for use in grid connected converters, such as active power filters. The main function of this technique is to detect a selective order of harmonics for control purposes. This method can detect and track the variations in the frequency of the signal and extract the time varying harmonics (5th and 7th harmonics).

Chung et al. (2010) proposed novel controller optimization algorithms for droop controllers and inverter output controllers for inverter interfaced DGs using Particle Swarm Optimization. Coordination between multiple DGs in the microgrid system can be realized using droop controllers, which can automatically find the amount of power sharing so that the microgrid can be stabilized quickly.

Dasgupta et al. (2011) proposed a novel current control technique to control both active and reactive power flow from a renewable energy source feeding a microgrid system through a single phase parallel connected inverter. This power control property facilitates the efficient usage of renewable energy in a microgrid. The proposed current controller is simple to implement and gives superior performance over the conventional current controllers.

Kulkarni & John (2013) presented a proportional resonant integral controller for inverter current control that mitigates lower order harmonics. In addition its design methods are also proposed. This controller eliminates the dc component in the control system. Magnitude of third harmonic is reduced from 7.34% to 3.47%.
Zhou et al. (2014) discussed a new PWM technique, named selective harmonic compensation, which actively compensates the power system background harmonics and still operates at very low switching frequencies. PWM current has noticeable fifth and seventh harmonics of 6.1% and 3.72%, respectively. The THD of line current obtained by this method has a much better performance (5.3%).

Yang et al. (2015) proposed a frequency adaptive selective harmonic control scheme which can be designed for grid connected inverters to optimally mitigate feed in current harmonics. The hybrid scheme consists of multiple parallel recursive order harmonic control modules with independent control gains, which is optimally weighted in accordance with the harmonic distribution. The current THD obtained is analysed for frequency variations ±1Hz.

Anwar et al. (2015) presented a strategy to eliminate harmonics from the grid current and the voltage of the Point of Common Coupling (PCC) for microgrid applications. The position of the harmonics reduction unit is selected so that it reduces the harmonics level of the grid current and PCC voltage harmonics irrespective of the placements of the renewable energy sources in the microgrid. Conventional inverter is employed on this scheme for control purpose.

From the above literature survey, it is concluded that different controllers are introduced for stabilization and elimination of harmonics in grid connected inverter. Most of the papers are concentrating on the harmonics at grid side not in inverter output side. Most of the integration of RES to grid is done through boost converter. Single stage optimized converter can be used to improve power transfer from input to output. Further the
harmonics are analyzed only at single value of N. The application of proposed technique for parallel connected RES to grid is not discussed in the literature.

1.7.3 Matrix Converter and Grid Connected WECS

Zhou & Danwei (2002) analysed the relationship based on modulation signals and space vectors, the switching pattern and the type of carrier distribution of zero vectors. The different zero-sequence signal is systematically established between Space Vector Modulation and three phase carrier based pulse width modulation. All the relationships provide a bidirectional bridge for the transformation between carrier-based PWM modulators and SVM modulators.

Cardenas & Pena (2004) presented a sensorless vector-control strategy for an induction generator in a grid connected WECS based back-to-back PWM inverter. The sensorless control system is based on a Model Reference Adaptive system (MRAS) observer to estimate the rotational speed. Requirement of regulation of dc link voltage using a PI fuzzy controller and high output current ripple in the above converter can be avoided if direct AC-AC converter is used.

Muller et al. (2005) presented a novel time-discrete modulation method based on real-time prediction calculation to select the switching states of MC. Using this approach, unity displacement factor is achieved at the supply side with minimum line current distortion with the load of induction motor.

Yoon & Sul (2006) presented a carrier-based modulation method for a MC. Using the offset voltage and changing the slope of carrier, it is possible to synthesize the sinusoidal input currents with the unity power factor and desired output voltages. To acquire the maximum transfer ratio for
the MC, control of the input current waveform is sacrificed. The THD of the input current becomes large in the order of 30.7%, which is still a much better number compared with that of a diode rectifier based VSI.

Comanescu & Xu (2006) presented two novel sliding mode model reference adaptive system observers for speed estimation in a sensorless vector controlled induction machine drive. Both methods use the flux estimated by the voltage model observer as the reference and construct sliding mode flux observers that allow speed estimation. The proposed estimators seem to be very robust and easy to tune.

Arias et al. (2007) described the origin of distortion effects for a MC with current sign based commutation and gives a novel approach to the method that can eliminate the distorting effects to give a power converter having excellent linear behaviour. The effectiveness of compensation techniques are illustrated for both an open loop MC driving a passive load and a MC as part of a vector controlled drive.

Sato et al. (2007) insisted on the instantaneous effective power control method to compensate the input voltage disturbances, in which the instantaneous effective power is kept constant by controlling the input current. This method is to control the stability of the system. THD of output current is 3.81%, fifth harmonic current is 5% and seventh harmonic current is 3%.

Lee & Blaabjerg (2008) presented a new and simple method for sensorless control of MC drives using a power flowing to the motor. To improve low speed sensorless performance, the nonlinearities of a MC drive are modelled using a power quality power transformation and compensated using a reference power control scheme.
Cardenas et al. (2008) analyzed on the performance of several model reference adaptive system observers for sensorless vector control of doubly-fed induction machines with PWM inverter. The stator current and rotor current model observer are compared and finally insisted that rotor current model observer is the best control methodology for grid connected operation.

Lee et al. (2008) presented direct SVM method to achieve the required displacement angle between input voltage and input current of MC for three phase inductive load. With this new SVM method, the near unity main input power factor region is enlarged, beside the higher power factor at the lower output power region.

Pena et al. (2009) presented a topology for a grid connected generation system, based on two doubly fed induction machines. It is implemented using an indirect matrix converter. The input stage is connected to the grid and provides the required dc voltage for the output stages. SVM is used for the input stage and produces the maximum dc voltage, with unity power factor operation at the grid side.

Cardenas et al. (2009) presented a new control system to regulate the reactive power supplied by a variable speed wind energy conversion system, based on an induction generator fed by a matrix converter. The control system is based on an input current observer, implemented using an estimation of the modulation matrix and a nonlinear control loop that regulates the displacement angle at the MC input. The voltage transfer ratio (ratio of output to input voltage) has a relatively large variation between 0.15 and 0.8.
Cardenas et al. (2009) presented the performance of a grid connected WECS with rotor current model observer on a Doubly Fed Induction Generator (DFIG) fed by a MC. The MC is operated close to unity power factor at the grid side. Stability issues related to the operation of the MC in the proposed WECS are discussed. The maximum achievable voltage transfer ratio is limited mainly by the MC and the commutation issues.

Kim et al. (2010) proposed a new PWM method for the matrix converter using the two higher line-to-line voltages as the virtual dc-link voltages. The virtual dc-link voltages adjacent to the output voltage reference are introduced to reduce output current switching ripples. The total harmonic distortion of output current is 16.91% at a voltage transfer ratio of 0.8.

Nguyen et al. (2011) proposed a new direct SVM method to achieve the required displacement angle between the input voltage and input current of the MC fed three phase load. Compensation algorithm I is based on using the input filter and power supply parameters to estimate the optimal compensated angle. Compensation algorithm II is subsequently proposed using a Proportional Integral (PI) controller to overcome the drawbacks presented in compensation algorithm I. Steady state and transient responses are discussed for both algorithms. PI controller based compensation algorithm gives more stability.

Friedli et al. (2012) introduced the methodology and the results of a comprehensive comparison of a Direct Matrix Converter (DMC), an indirect MC, and a voltage dc-link Back to Back converter (V-BBC) for a permanent magnet synchronous motor drive. The DMC allows for the highest efficiency in the considered switching frequency range. The higher achievable power density and power to mass ratio of MCs are achieved when compared to the
V-BBC. The MC enables, a particularly at higher switching frequencies, better performance than the V-BBC.

Empringham et al. (2013) presented a review of the current state of matrix converter technologies. The matrix converter has also been applied to drive the rotor circuit of a DFIG for wind turbine applications using direct and indirect matrix converters. This technique has the advantage that a relatively low power four-quadrant power converter can be used to control a high power generator system.

Xiao & Rahman (2013) proposed a new sensorless direct torque and flux controlled interior permanent magnet synchronous machine drive fed by a MC and unity power factor on the power supply side of MC, achieved through closed-loop compensation of the input displacement angle. The input and output voltage vectors are modulated with the indirect space vector modulation technique.

Rivera et al. (2013) compared performance of the well established space vector modulation technique and model predictive control. The assessment is made by measuring and comparing output and input currents and voltages with the same voltage source and load current conditions. THD is less in model predictive control compared to SVM technique. The selection of a weighting factor value is still an important issue in model predictive control.

Nguyen & Lee (2014) proposed an indirect matrix converter topology with dual three-phase outputs and its effective carrier-based pulse width modulation method. THD of output voltage and input current with output frequency variations are discussed.
Grigoletto & Pinheiro (2014) presented a new flexible arrangement of three-phase voltage-fed back to back mass produced power converter modules with reconfiguration switches for grid connected WECS. The main feature of the proposed flexible arrangement is the expanded reactive power capability limits.

From the above literature survey, it is observed that different observers were applied to MC fed induction motor/three phase load/grid applications. It is identified that rotor based sensor less control gives a better performance for grid connected operation. Different techniques are available for input power factor correction of MC. The literatures on MC are discussing with its stability issues or only with its input power factor compensation without any optimization. For parallel connected WECS to grid, similar type of converter topologies are used and analysed.

1.7.4 Hybrid System

Giraud & Salameh (2001) reported the performance of grid connected residential Wind–Photovoltaic system with battery storage and it satisfies the load and provides additional energy to the storage or to the grid. It discusses on system reliability, loss of supply and effects of the randomness of the wind and the solar radiation on system design with conventional dc-ac converter for power conversion.

Daniel et al. (2004) considered isolated renewable energy systems based hybrid wind solar sources reliable options instead of wind diesel systems. The isolated hybrid scheme employed a simple three phase square wave inverter to integrate a photovoltaic array with a wind-driven induction generator to supply a three-phase remote load. A dc–dc step-up converter is
interposed in the proposed system between the PV array and the inverter to maintain the PV array voltage constant.

Arutchelvi & Daniel (2006) proposed a hybrid PV array excited wind-driven induction generator with dc-dc step-up converter for maintaining a constant resistive load voltage. A closed loop PI controller is designed to automatically vary the duty-cycle of the dc-dc converter. A detailed d-q axes model of the proposed scheme is developed and employed.

Chen et al. (2007) introduced a novel multi-input inverter for the grid connected hybrid photovoltaic/wind power system in order to simplify the power system and reduce the cost. The proposed multi-input inverter consists of a buck/buck-boost fused multi-input dc–dc converter and a full bridge dc–ac inverter. The total harmonic current distortion is 4.5%.

Gajanayake et al. (2009) designed a ZSI-based flexible DG system for integrating renewable energy sources into the grid for improving power quality of the grid. Grid current spectrum is improved with reduced lower order harmonic components, current THD are reduced to 5.72% and 3.6%, respectively, for V1 and V2 voltage improvement modes. The voltage harmonic spectrum is improved as voltage THD is reduced to 1.59% and 1.81% with the V1 and V2 control methods, respectively.

Vilathgamuwa et al. (2009) presented a modulation and controller design method for paralleled Z-source inverter systems applicable for alternative energy sources like solar cells, fuel cells, or variable-speed wind turbines with front-end diode rectifiers. A modulation scheme is designed based on simple shoot-through principle with interleaved carriers to give enhanced ripple reduction in the system. Load voltage THD is 2.99% and grid current THD is 4.21%.
Liu et al. (2010) reviewed both the wind power and PV power generation techniques and their maximum power point tracking methods. For the wind power generation branch, a new doubly excited permanent magnet brushless machine is used to capture the maximum wind power using online flux control. For the PV power generation branch, a single ended primary inductance converter is adopted to harness the maximum solar power by tuning the duty cycle. The corresponding power improvement is from 3% to 25.1%.

Bae & Kwasinski (2012) proposed dynamic modelling and control strategy for a sustainable micro grid primarily powered by wind and solar energy. A current source interface multiple input dc-dc converter is used to integrate the renewable energy sources to the main dc bus.

Cespedes & Sun (2014) presented small signal impedance modelling of grid connected three phase converters for wind and solar system stability analysis. A converter is modelled by a positive sequence and a negative sequence impedance directly in the phase domain. Grid connected voltage source converter impedance models can be used to assess system level converter grid compatibility and power quality.

Rajansingaravel & Daniel (2015) investigated a new topology of a hybrid distributed generator based on photovoltaic and wind driven permanent magnet synchronous generator. The sources are connected together to the grid with the help of a single boost converter followed by an inverter. Two low cost controllers are also proposed for the new hybrid scheme to separately trigger the dc-dc converter and the inverter for tracking the maximum power from both sources. The maximum voltage and current THD are 1.8% and 4.6% respectively.
From the above survey, it is inferred that mostly single converter is used to connect both RES to load. Independent control of converters for both supply systems is not possible for improving input power factor and THD and also the output THD. Conventional converters are mostly used for integration and also THD is discussed in grid side under single load condition.

1.8 RESEARCH GAP IDENTIFIED IN LITERATURE SURVEY

The performances of grid with integration of multiple RES connected through converters depend on the type of converter and control techniques.

Research works for selective harmonic elimination problem is concentrated on single phase inverters and its control techniques and also for limited number of harmonics to be eliminated with limited Modulation Indices. It is required to propose an optimum PWM technique to eliminate specific lower order harmonics with possible number (odd or even) of odd harmonics (N) and modulation indices value in SHEPWM inverter fed grid. All the parameters regarding harmonic performance in output side of inverter have to be studied. SHEPWM inverter without output filter is required to explain the actual performance of the system.

Most of the research works in integration of PV system to grid are focused on voltage THD in grid side through boost converter with PWM inverter. For connecting PV system to grid, single stage optimized inverter is to be proposed. Voltage and current THD and lower order harmonic analysis can be done in converter side. Elimination of harmonics for different value of N has to be included in the grid connected inverter. For parallel operation of PV systems connected to grid, different inverter topologies have to be added to validate the performance of proposed inverter.
Most of the research works in WECS fed grid are concentrated on stability issues or input power factor correction and also through AC-DC-AC converter with three phase load. Integrating WECS to grid, single stage AC-AC conversion is required to avoid the DC link voltage. It is needed to study the performance in grid side as well as converter output side of grid connected WECS using MC under different local load condition. Optimization technique can be included in the control technique to improve their performance further. A control method is to be introduced to improve input power factor as well as harmonic performance of both input and output of converter. Different converter topologies or proposed converters are to be included in parallel connected WECS to study the performance.

From the Literature survey, conventional converters are mostly used to integrate RES (PV and wind systems) to grid in hybrid system. It is required to replace the system with optimized converters and study the output performance at local load side, grid side and input performance of WECS. It provides independent control and study of converters used for connecting PV and wind system to grid.

1.9 OBJECTIVE OF THE THESIS

This dissertation explains converters proposed for hybrid system and integrated approach to improve the performance. The specific objectives of this research work are

- To propose an optimized Selective Harmonic Elimination (SHE) PWM (Genetic Algorithm based) inverter for grid connected solar energy system to reduce harmonics for different N (number of odd harmonic) values and validate the results using experimental prototype. To model an integrated approach of
inverters to improve the performance of grid connected solar energy systems.

- To propose an optimized Proportional Integral (PI) based matrix converter for grid connected Wind Energy Conversion System (WECS) to improve the input power factor and analyse the harmonics under different load condition. To compare the performance of integrated approach of combined conventional and optimized matrix converter connected wind systems.

- To model optimized matrix converter with Model Reference Adaptive System (MRAS) observer and PI controller to improve input power factor and output performance of grid connected WECS under different local load condition.

- To incorporate optimized SHEPWM inverter and optimized matrix converter for Hybrid solar and wind energy system to improve input power factor and to reduce load harmonics.

1.10 ORGANIZATION OF THE THESIS

The thesis is organised as follows.

Chapter 1 presents introduction about RES, power quality issues and grid connected converters and inverters for wind and solar energy systems. The detailed literature survey is presented.

Chapter 2 deals with the modelling of SHEPWM inverter for PV system fed grid with different values of N and MI with calculation of optimized switching angles using GA matlab code and also applying the modelled inverter to integrated approach of grid connected PV systems to analyse the harmonics.
Chapter 3 deals with the input power factor correction in MC for WECS fed grid using GA based PI controller under normal and light load and presents detailed harmonics study in input and output side of converter and also applies that MC in grid connected wind energy systems to analyse the performance of MC.

Chapter 4 presents the modelling of MRAS and PI controller based MC for WECS fed grid and analyse the harmonic performance of input and output of converter, grid side and also input power factor of MC under different load conditions.

Chapter 5 models the hybrid system with proposed optimized SHEPWM inverter and optimized MC and compares with conventional approach in terms of harmonics and power factor.

Chapter 6 summarizes the work carried and future scope of the work.