ISSN 2229-5518

Renewable Sources Grid Interfacing System

Fariha Khan, Hamza Talha, Haroon Rasheed

Abstract— Energy demand throughout the world has been increasing rapidly. The present energy sources such as oil reserves, coal deposits, natural gas are exhaustible and getting limited in supply. Therefore, there is an urgent need to conserve available resources and utilize energy as much as possible. In this paper we propose "Renewable Sources Grid Interfacing System" for effective conservation of renewable energy resources. We exploit multiple energy sources at the same time implying load sharing principle. This investigation explores the aspects of Load Sharing phenomenon of a grid connected Hybrid Energy System (HES). In our model solar and wind energy sources have been considered. The acquired results depict that the performance can be improved by changing the phase angle and modulation index of grid inverter. Hence Renewable energy sources such as solar and wind energy can play an important role in eliminating the energy crisis in our country if utilized properly. Most of the renewable energy systems are operated in stand-alone mode, which only supply power to fixed loads. Interconnection of this system with utility is the current design trend.

Index Terms— Grid Interfacing, Sine Wave Inverter, Load Sharing, Selective Harmonic Elimination, Hybrid Energy System, Renewable Energy, Boost Converter, Isolated Power Supply

1 INTRODUCTION

THE Renewable energy sources are intermittent in nature hence it is therefore a challenging task to integrate renewable energy resources into the power grid. Some of the challenges and issues associated with the grid integration of various renewable energy sources particularly solar photovoltaic and wind energy conversion systems [10] are: (i) Maintaining power quality (Reduction in harmonics, and control of frequency and voltage fluctuations) (ii) Power fluctuation (Elimination/Control of small time power fluctuations and long time or seasonal power fluctuations) (iii) Storage (iv) Protection issues (v) Optimal placement of renewable energy sources [10].

It is more beneficial to use wind/solar hybrid system than single wind or solar power generation since it suppresses rapid change in the output power of the single source such as the wind turbine system [6].

Grid interface of the hybrid system with battery storage improves system reliability [7], [8]. Power system frequency stability relies on the balance between the active power output of the generators and the active power consumed by the loads. Therefore, it is essential to reduce the renewable energy power fluctuation up to a certain range [5].

The power-electronic technology plays a significant role in distributed generation and in integration of renewable energy sources into the electrical grid, and it is rapidly expanding as these applications become more integrated with the grid-based systems.

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During the last few years, there have been major advancements in power which are primarily due to two factors. The first one is the development of fast semiconductor switches that are capable of high frequency switching and high power handling capability. The second factor is the introduction of real-time computer controllers that can implement advanced and complex control algorithms effectively. These factors together have led to the development of cost-effective and grid-friendly converters [9].

In this paper solar and wind energy sources have been considered under study. The aim is to develop a system that integrates different renewable energy sources together with the grid to deliver power to the load. The system will deliver power primarily from renewable energy sources depending on their availability. Power from each of the source is added to deliver the load. If these sources are not sufficient then the remaining power will be delivered from the grid. If the generation is greater than the demand, the excess power can be fed through a meter back to the grid. Scheme of hybrid energy system and grid interfacing converter as shown in Figure 1 can be defined by the combination of its major components:-
(i) Solar PV array (ii) Wind turbine (iii) Grid

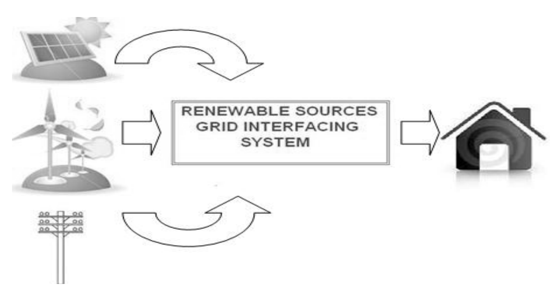

Fig. 1. Pictorial representation of Grid Interfacing Converter

ISSN 2229-5518

A system is developed that integrates different power sources and does not switch between different sources but instead it combines all renewable sources as well as grid to deliver power to the load.

Power output of the system can be controlled by controlling the real power delivered by each individual source. Hence the output will be the sum of each individual source. This will tend to minimize the usage of electricity from the utility company, at the same time increasing the utilization of renewable energy sources as much as possible.

A high efficiency inverter is developed that would be capable of producing sine wave output to store and convert different forms of energy to AC. The inverter developed will vary its power output depending on its input. Thus it is intended to control the real power delivered by the inverter. This will hence control the amount of renewable energy utilized by the system. The main target will be to utilize the renewable energy as much as possible. If the output of the inverters is greater than the demand than the extra energy will be fed to the grid.

The inverter is made using H-bridge topology with high voltage and low voltage sides isolated from each other. The output of the H-bridge can be made sinusoidal by using selective harmonic elimination technique in addition to a LC filter. The system performance parameters are stated in Table 1.

TABLE 1
PERFORMANCE PARAMETERS

Parameter	Specification
Input	24 Volts DC
Output	230 Volts RMS
Frequency	50 Hertz
Power	500 Watts

2 TYPES OF RENEWABLE ENERGY POWER SYSTEMS

2.1 Stand-Alone System

Stand-alone systems as shown in Fig. 2 are used in remote areas with no access to a utility grid. Conventional power systems used in remote areas often based on manually controlled diesel generators operating continuously or for a few hours. Extended operation of diesel generators at low load levels significantly increases maintenance costs and reduces their useful life [2].

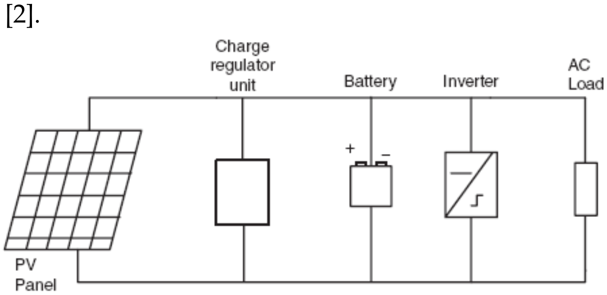

Fig. 2. Stand-Alone System [2]

2.2 Hybrid Energy System

Renewable energy sources such as photovoltaics (PV) can be added to remote area power systems using diesel and other fossil fuel powered generators to provide 24-hour power economically and efficiently. Such systems are called "hybrid energy systems."

The combination of RES, such as PV arrays or wind turbines, with engine-driven generators and battery storage, is widely recognized as a viable alternative to conventional remote area power supplies as shown in Fig. 3. These systems are generally classified as hybrid energy systems (HES). They are used increasingly for electrification in remote areas where the cost of grid extension is prohibitive and the price for fuel increases drastically with the remoteness of the location.

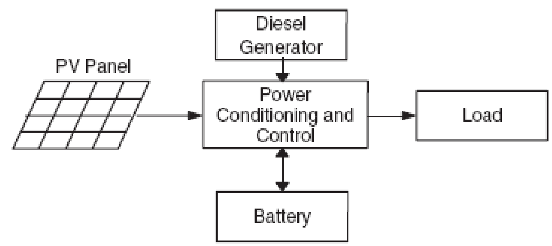

Fig. 3. Photovoltaic diesel Hybrid System [2]

2.3 Grid-Connected System

The utility interactive inverters not only conditions the power output of the PV arrays but ensures that the Renewable energy system output is fully synchronized with the utility power as shown in Fig. 4 [2]. These systems can be battery less or with battery backup. Systems with battery storage provide additional power supply reliability.

The grid connection system is gathering momentum because of various rebate and incentive schemes. This system allows the consumer to feed its own load utilizing the available solar energy and the surplus energy can be injected into the grid under the energy by back scheme to reduce the payback period. Grid-connected systems can become a part of the utility system. The contribution of solar power depends upon the size of system and the load curve of the house. When the renewable energy system is integrated with the utility grid, a two-way power flow is established. The utility grid will absorb excess PV power and will feed the house during nighttime and at instants while the renewable power is inadequate. The utility companies are encouraging this scheme in many parts of the world.

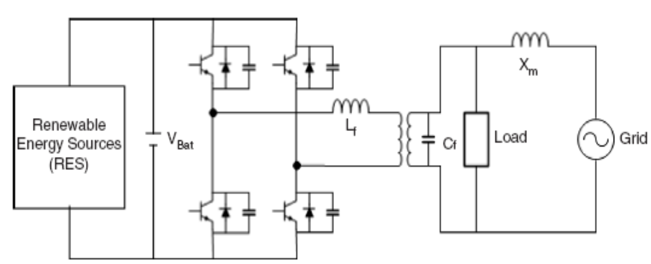

Fig. 4. Grid connected System [2]

ISSN 2229-5518

3 System Design

The requirement is to design a system which can integrate various forms of renewable energy sources with electrical grid in order to fulfill load demands. Because the system is focused on effective utilization of energy, the system designed should have very high efficiency. In other words great amount of study and research is done in order to prevent losses in the system.

Because the system is designed for domestic utilization, therefore it must produce a pure sine wave output to supply harmonic free power to the household load.The size of the system is to be kept as small as possible so that it can be easily installed inside any house. The cost of the system should also be kept low so to make it as affordable as possible.

For the effective utilization of renewable energies, the system will deliver power primarily from the renewable energy sources; if this power is insufficient then the deficient power will be taken from the electrical grid. This will utilize renewable energy sources as much as possible.

Most renewable energy sources produce DC power which should be converted to AC to be delivered to the load. Moreover, the task of delivering power primarily from the renewable energy sources dictates that the real power delivered to the load from these sources should be controlled. The remaining power will be drawn from the grid by the load. Summarizing the above, an inverter is needed whose output power is to be controlled.

The system is implemented in such a way that the DC power from renewable energy sources is fed directly to the inverter. The inverter's output is connected to the load while the grid is connected directly to the load. Output power of the inverter is controlled by varying its output phase angle δ with respect to the grid.

3.1 Grid Interfacing System

The system should be capable of converting DC input of 24V to AC output of 230V at 50Hz.The DC power is fed to a DC-DC boost converter with voltage gain. This simply boosts 24V DC to about 350V DC. The output of this converter is then fed to the inverter stage which converts it to 230V AC. The system implementation can be easily understood with Figure 5.

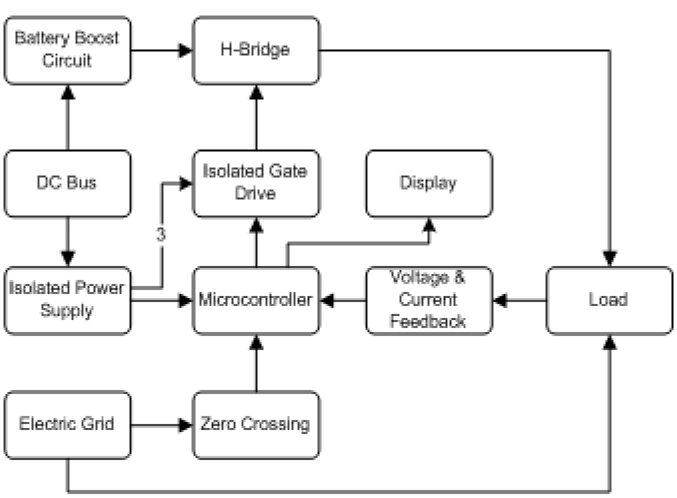

Fig. 5. Block Diagram of the Designed System

3.2 Battery Boost Converter

Battery boost circuit is design is based on a PWM controller IC that is TL494. The IC applies a variable duty cycle pulses of 100 kHz to the step up transformer. On the secondary side of the transformer, the AC signal is rectified and filtered to make it a smooth DC. This DC is then fed to the H-bridge.

The transformer also has a low voltage winding for feedback. The output of this winding is rectified and then fed to a RC network. The internal error amplifier of the PWM controller IC senses the voltage of this RC network and changes the duty cycle accordingly.

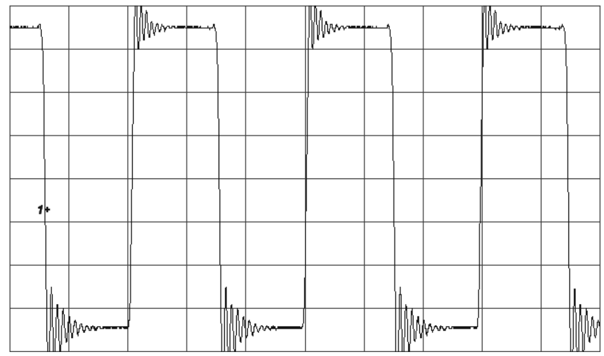

Fig. 6. Boost Converter Output

3.3 Ferrite Core Transformer

Unlike the transformers using metallic stampings, where the core area can be adjusted by selecting the proper stack height, ferrite core of a particular size has an unalterable core area. Thus the design procedure for ferrite transformers is modified to suit this restriction [11]. The maximum power handling capacity of a ferrite core transformer can be expressed in terms of the transmissible power P as:

$$P = K * f * Bm * J * Kw * Aw * Ac * 10^{-4} \quad (1)$$

Where

K = Operating waveform constant

f = Operating frequency

Bm = Maximum flux density swing of core material in Wb/m2

J = Current density of wire in amp/cm^2

Kw = Window area utilization factor

Aw = Window area of core in cm^2

Ac = Core area in cm^2

TABLE 2

Transformer Voltage Comparison

Frequency (kHz)	Output (Volts)
40	190
60	220
100	300
150	270

ISSN 2229-5518

3.4 The H-Bridge

The output of the battery boost converter that is 350V DC is fed to the H-bridge. The H-Bridge design uses 4 IGBTs 25n120. IGBTs are used because high voltages are supplied to the H-Bridge so a device with high reverse blocking voltages is required. Another factor is that the device should be capable of withstanding any possible voltage spikes. 25n120 is capable of blocking 1200 V and has the current rating of 36 A. The pulses for driving the IGBTs are provided from the microcontroller through an isolated gate-drive circuitry. The H-Bridge needs to operate at a high frequency for effective harmonic elimination.

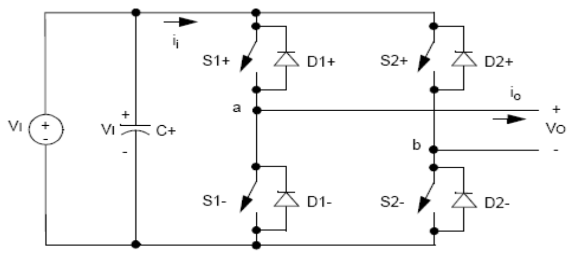

Fig. 7. Simple H-Bridge Topology [2]

3.5 Selective Harmonic Elimination (SHE)

The angles α1 to αn are calculated for different values of vo/vi. These values are programmed in the microcontroller in the form of lookup tables. The table contains all the delays required for all pulse generations. Depending upon the ratio of vo/vi the values of all the delays are selected from the table.

For elimination of harmonics, timing must be very precise up to one instruction cycle. Every path of the code must take exactly the same number of instruction cycles. This also restricts to use of interrupts. For the above stated reasons separate dedicated microcontroller is required for sine wave generation.

To effectively eliminate harmonics and produce a pure sine wave at the output of the inverter Selective Harmonic Elimination (SHE) technique [12] is applied. In this method notches are created on the square wave at predetermined angles. The AC output voltage of a full-bridge inverter features odd-half and quarter-wave symmetry; therefore even harmonics are not present. To adjust the fundamental component and eliminate N-1 harmonics the output waveform should consist of N pulses per half-cycle. A large number of harmonic components can be eliminated if the waveform can accommodate additional notch angles. As shown in Figure 8, if it is wished to remove third, fifth and seventh harmonics together with controlling the magnitude of the fundamental component (where N=4) we need to solve the following equations:

$$\cos(1\alpha_1) - \cos(1\alpha_2) + \cos(1\alpha_3) - \cos(1\alpha_4) = \pi v_o/4v_i \quad (2)$$
$$\cos(3\alpha_1) - \cos(3\alpha_2) + \cos(3\alpha_3) - \cos(3\alpha_4) = 0 \quad (3)$$
$$\cos(5\alpha_1) - \cos(5\alpha_2) + \cos(5\alpha_3) - \cos(5\alpha_4) = 0 \quad (4)$$
$$\cos(7\alpha_1) - \cos(7\alpha_2) + \cos(7\alpha_3) - \cos(7\alpha_4) = 0 \quad (5)$$

where α_1, α_2, α_3 and α_4 are the angles to be solved, v_o is the output voltage of the full-bridge while v_i is its input. The general expressions to eliminate N-1 harmonics are given by:

$$-\sum_{k=1}^{N}(-1^k)\cos(n\alpha_k) = \pi v_o/4v_i \quad (6)$$

$$-\sum_{k=1}^{N}(-1^k)\cos(n\alpha_k) = 0 \quad for\ n = 3, 5, \ldots, 2N-1 \quad (7)$$

Where $\boldsymbol{\alpha}_1$, $\boldsymbol{\alpha}_2$, . . ., $\boldsymbol{\alpha}_N$ should satisfy $\boldsymbol{\alpha}_1<\boldsymbol{\alpha}_2<\ldots\ldots<\boldsymbol{\alpha}_N<\boldsymbol{\pi}/2$. The above equations for the calculation of angles cannot be solved analytically therefore an alternative approach is required. An application by the name "Magic Sine Wave" is used to calculate the firing angles.

Implementing SHE, first 26 harmonics were eliminated. Figure 9 shows the H-bridge output using SHE. Fig. 10 shows the frequency spectrum of the output. A second order low pass filter is added at the output to make the output waveform sinusoidal.

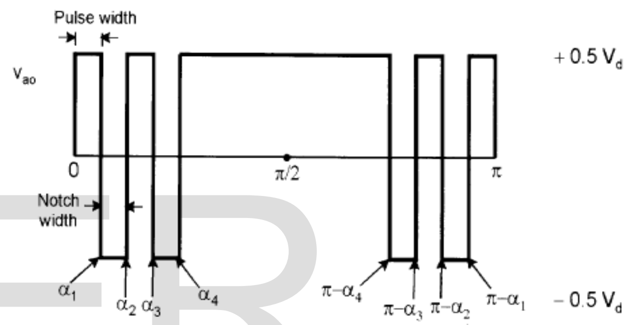

Fig. 8. Phase voltage wave for Selective Harmonic Elimination [1]

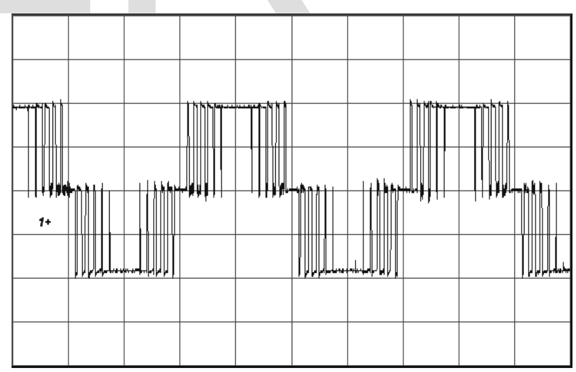

Fig. 9. H-Bridge output using Simple Harmonic Elimination

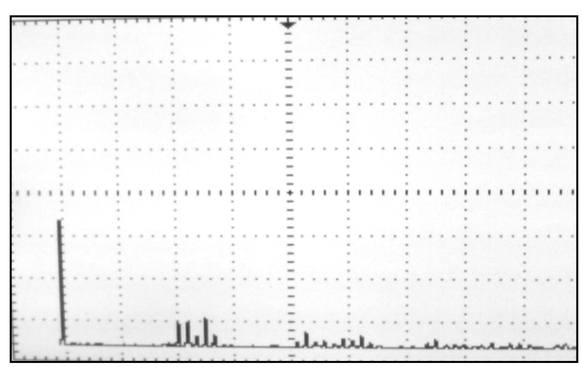

Fig. 10. First 26 Harmonics eliminated

ISSN 2229-5518

3.6 Load Sharing

The load sharing principle [3], [13] is used to control the power output of the inverter. The power is varied depending upon the input and load so that the output is made stable. The power output is controlled by changing the phase angle and modulation index of the inverter.

If the power output of the inverter is less than the demand, then the phase angle is adjusted to make the output of the inverter stable thus limiting the output power. The remaining demanded power is fed to the load by the grid. The power delivered by the inverter p is given by:

$$p = \frac{VinvVt}{Xi} \sin \delta \quad (8)$$

Where V_{inv} is the output voltage of the inverter, V_t is the grid voltage and δ is the angle between the grid voltage and inverter voltage. If the output power of the inverter is to be controlled the value of δ is to be varied keeping the inverter output voltage V_{inv} constant. By adjusting modulation index (M) and phase, the value of δ can be increased or decreased while keeping the value V_{inv} constant and thus varying the amount of power supplied by the inverter.

4 Conclusion

The objective was to utilize renewable energy sources as much as possible and at the same time minimizing electricity consumption from the utility company. The inverter was developed using a ferrite core transformer which had the advantage of very low losses, small size and less weight. The designed was developed on the basis of load sharing principle. The angle δ, the angle between inverter output voltage and grid voltage is varied to control the real power output of the inverter.

Selective harmonic elimination technique along with a LC filter was used to remove the harmonics from the output voltage. With the growing energy crisis, this will prove to be an effective solution especially for domestic users. The main noticeable effect will be the reduction in electricity bills. It will also ease the load on the utility company that provides electricity.

Acknowledgment

Deepest gratitude is owed to Mr. Shehzad Hafeezi (Vice President Mazik Global Inc.) for providing us with the ideas and resources also Dr. Haroon Rasheed (Head of Department, Bahria University, Karachi Campus) and Mr. Salman Zaffar (Assistant Professor, DHA Suffa University) for sound guidance without which we would never have had the chance to further our technical skills.

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