A Cuk-Sepic Based Modular Design Methodology For Smart Grid Inverters

A Project Report

Submitted by

VARUN. P - 0920105014

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(An Autonomous Institution Affiliated to Anna University of technology, Coimbatore.)

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Mr. Varun.P - Register No. 0920105014

Who carried out the project work under my supervision

Signature of the Head of the Department

....

Dr. Rani Thottungal

Signature of the Supervisor

....

for Mrs. M. Nirmala

Certified that the candidate with university Register No 0920105014 was examined in project viva voce Examination held on 27/04/2011

Internal Examiner

External Examiner

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING
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ABSTRACT

Power supply systems all over the world are facing challenging situations where they have to be extremely flexible, reliable and expandable. Existing grids have to be modified due to the growing proportion of distributed and renewable energy sources. Power electronic inverters are the key components to couple different energy conversion systems and to manage their operation. To fulfill the changing demands of the growing smart grids, new concepts for inverter design are needed. In this paper an innovative concept for future oriented power systems the modular inverter design is detailed. A Modular inverter design is presented for a modern power system which inputs power from both AC and DC Renewable resources, The Converter is the combination of Cuk-Sepic converters, the input from the source can be either buck or boosted or stabilized at the particular value, the inductor in circuit further provides the function of filter reducing Harmonics. The Inverter is the combination of two kinds of Inverters and it supports both symmetric and asymmetric loads. System works on the presence of both or any one of the Renewable resources, Furthermore; existing systems can be changed, rescaled and expanded easily. The system senses the load (symmetric or asymmetric) and switches between the Inverters (Three leg inverter or three leg inverter with Neutral point) according to the loads.

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ABBREVIATIONS

RES	Renewable Energy Source
DG	Distributed Generation
ECS	Energy Conversion System
CHP	Combined Heat Power
SEPIC	Single Ended Primary Inductor Converter
WEC	Wind Energy Converters
PWM	Pulse Width Modulation
PV	Photo Voltaic
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
PIC	Peripheral Interface Controller
MPPT	Maximum Power Point Tracking
THD	Total Harmonic Distortion
IGBT	Insulated Gate Bipolar Transistor

CHAPTER 1

1. INTRODUCTION

Power generation and power distribution systems worldwide are facing new significant challenges. On the one hand power demand is increasing enormously, caused by the worldwide economical growth. On the other hand the conventional fossil energy sources are limited and running out in close future. Over the last 30 years, global primary energy consumption has almost doubled. These challenges led to vast investigation efforts in the field of renewable energy sources (RES) and therewith towards sustainable and environmentally friendly technologies. Rising fossil fuel prices and convenient national economic conditions support this evolution. The trend in power systems is developing towards distributed generation (DG). This means that the conventional few large power plants are step by step replaced by many small energy conversion systems (ECS), which are located close to the energy consumers. The main DG power sources applied today are e.g. hydropower turbines, wind turbines, biomass power plants, photovoltaic solar systems, and combined heat power (CHP) micro turbines. Also fuel cells, gas micro-turbines, solar-thermo power, as well as hybrid power systems consisting of a combination of different sources are available. Future power systems therefore need to be reliable and easy to maintain. Investigations in the field of renewable energies and distributed generation show that deep technologic changes are still needed.

Electricity losses in India during transmission and distribution are extremely high and vary between 30 to 45%. In 2009-10, electricity demand outstripped supply by 7-11%. Due to shortage of electricity, power cuts are common throughout India and this has adversely effected the country's economic growth. Despite an ambitious rural electrification program, some 400 million Indians lose electricity access during blackouts. While 80 percent of Indian villages have at least an electricity line, just 52.5% of rural households have access to electricity. In urban areas, the access to electricity is 93.1% in 2008. The overall electrification rate in India is 64.5% while 35.5% of the population still live without access to electricity. According to a sample of 97,882 households in 2002, electricity was the main source of lighting for 53% of rural households compared to 36% in 1993.

1.1 SMART GRID

A smart grid is a form of electricity network utilizing digital technology. A smart grid delivers electricity from suppliers to consumers using two-way digital communications to control appliances at consumers homes; this could save energy, reduce costs and increase reliability and transparency if the risks inherent in executing massive information technology projects are avoided. The "Smart Grid" is envisioned to overlay the ordinary electrical grid with an information and net metering system that includes smart meters. Smart grids are being promoted by many governments as a way of addressing energy independence, global warming and emergency resilience issues. The idea of two way communications from suppliers to consumers to control appliances is not new, and systems have been implemented using analog technology for many years. The growth of an extensive digital communication network for the internet has made it practical to consider a more sophisticated type of smart grid. The increased data transmission capacity has made it conceptually possible to apply sensing, measurement and control devices with two-way communications to electricity production, transmission, distribution and consumption parts of the power grid at a more granular level than previously. Like existing utility grids, a smart grid includes an intelligent monitoring system that keeps track of all electricity flowing in the system, but in more detail. Like the existing grid, it also has the capability of integrating renewable electricity such as solar and wind, but has the potential to do so more effectively

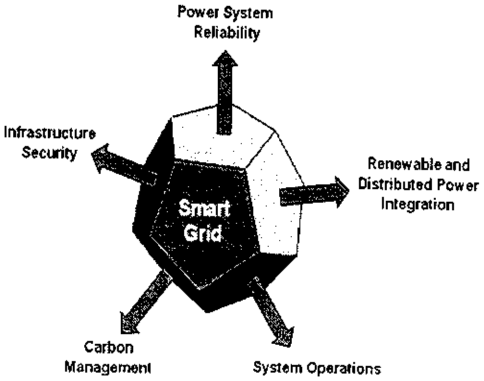


Figure 1. 1 Functions of Smart Grid

1.1.1 Smart Energy Demand

Regardless of the future demands, most existing strategies in inverter design today are nevertheless still adjusted to fixed customized structures. Most inverters can handle defined sources and support certain load types only. They can not be adjusted in size easily. Anyway, future inverters need to be flexible. They must be able to support any local conditions. The European research initiative "Smart Grids" claims integration and interoperability among others, as the basic needs for a secure future power supply. Smart energy demand describes the energy user component of the smart grid. It goes beyond and means much more than even energy efficiency and demand response combined. Smart energy demand is what delivers the majority of smart meter and smart grid benefits. Smart energy demand is a broad concept. It includes any energy-user actions to:

- Enhancement of reliability
- Reduce peak demand
- Shift usage to off-peak hours
- Lower total energy consumption
- Actively manage electric vehicle charging
- Actively manage other usage to respond to solar, wind, and other renewable resources, and
- Buy more efficient appliances and equipment over time based on a better understanding of how energy is used by each appliance or item of equipment.

All of these actions minimize adverse impacts on electricity grids and maximize consumer savings. Smart Energy Demand mechanisms and tactics include:

- Smart meters
- Dynamic pricing
- Smart thermostats and smart appliances
- Automated control of equipment
- Real-time and next day energy information feedback to electricity users
- Usage by appliance data
- Scheduling and control of loads such as electric vehicle chargers, home area networks

1.2. INVERTER AS POWER ELECTRONIC INTERFACE

Power electronic inverters are the key components to couple different energy conversion systems and to manage their operation. Many of the distributed energy sources and storages are DC sources, like photovoltaic systems, batteries or fuel cells. Also nearly all AC sources are connected to the grid by decoupling of the state variables (frequency and voltage) through an intermediate DC circuit or even a DC bus. As in Figure 1.2, The DC sources and intermediate DC circuits have to be connected to the grid by the use of inverters, converting DC voltages to AC voltages with frequency ratings and voltage levels of the grid. Inverters are most essential components of distributed power systems. Inverters are the dynamic actuators responsible for the control and management of distributed energy sources connected to the grid or load. From the system level point of view, inverters can be characterised as the interfaces between ECS and the grid. Interfaces as the coupling points between systems, are the elements responsible for adaptability and flexibility of systems and therefore have to be analyzed with special attention. The inverter may include an internal rectifier, if AC sources are connected at the ECS side, or a DC/DC converter to adjust the DC voltage levels of applied DC sources to the voltage of the intermediate circuit. Beside the power electronic components also a control and management system is needed. The control unit keeps functions to process the measured values and to generate switching commands for the power electronics hardware. The management system is also responsible for the interfacing of the inverter automation functions to super ordinate control systems and user interfaces.

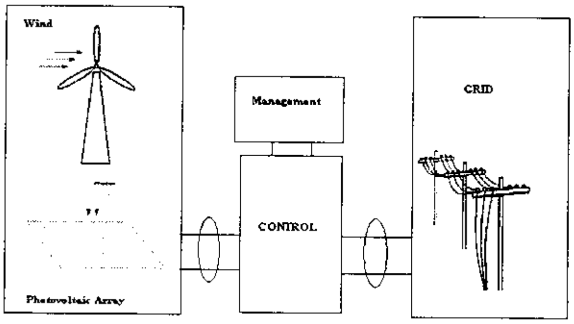


Figure 1.2 Inverter as a Interface between Source and Grid

1.3. OBJECTIVE OF THE PROJECT

A basic approach to fulfil the demands of flexible and adaptable integration is the modular design of inverter systems detailed in this paper. Modular design of inverters offers easy expandability, adaptability and advanced reliability of power supply systems. Further more by the proposed modular design strategy, costs in design, production, installation and operation can be reduced significantly.

In this paper, an alternative multi-input rectifier structure is proposed for hybrid wind/solar energy systems. The proposed design is a fusion of the Cuk and SEPIC converters and inverters are switched automatically according to the load The Inverter systems supports both symmetric and asymmetric loads. The features of the proposed topology are:

1) The inherent nature of these two converters eliminates the need for separate input filters for PFC

2) It can support step up/down operations for each renewable source (can support wide ranges of PV and wind input)

3) System works on the presence of both or any one of the Renewable resources

4) Individual and simultaneous operation is supported. The circuit operating principles will be discussed in this paper.

Also the performance of the proposed system was analysed by examining the output voltage and input current waveforms using MATLAB/SIMULINK Software and suitable Hardware prototype is developed for the system.

1.4. LITERATURE SURVEY

The topology for the change towards DG and RES is further pushed forward by the actual ailing status of the existing conventional power plants and distribution systems, which have to be reworked is described by M. N. Marwali, J.-W. Jung, and A. Keyhani, in their paper "Control of Distributed Generation Systems, Part II: Load Sharing Control" When a source is unavailable or insufficient in meeting the load demands, the other energy source can compensate for the difference.

In the paper of D. Das, R. Esmaili, L. Xu, D. Nichols, "An Optimal Design of a Grid Connected Hybrid Wind/Photovoltaic/Fuel Cell System for Distributed Energy Production" the concept of Several hybrid wind/PV power systems with MPPT control have been proposed and discussed in works . Most of the systems in literature use a separate DC/DC boost converter connected in parallel in the rectifier stage to perform the MPPT control for each of the renewable energy power sources, has been proposed.

In Y.M. Chen, Y.C. Liu, S.C. Hung, and C.S. Cheng,"Multi-Input Inverter Grid-Connected Hybrid PV/Wind Power System," A simpler multi-input structure has been suggested by that combine the sources from the DC-end while still achieving MPPT for each renewable source. The structure proposed is a fusion of the buck and buck-boost converter.

Similarly in dos Reis, F.S., Tan, K. and Islam, S.,"Using PFC for harmonic mitigation turbine energy conversion systems"The systems in literature require passive input filters to remove the high frequency current harmonics injected into wind turbine generators. The harmonic content in the generator current decreases its lifespan and increases the power loss due to heating. Since the power system is continuously changing regarding the structure, the sources and the loads, the development of very flexible ECS integration concepts is necessarily needed. These concepts need to be adaptable to every supply situation with minimal effort in design and implementation. The inverter is considered as the essential component in optimization of RES and distributed energy resources (DER), since it is the active control element at the connection point between the sources and the grid or loads. Developments in the field of power electronic devices in combination with modern control strategies for inverters offer a variety of operation strategies for efficient system management.

1.5. ORGANISATION OF THE THESIS:

This report presents a Cuk -Sepic based Inverter system .Chapter 1 gives an overview of Smart Grid and its detailed features to answer the power problems in future and importance of power electronic inverter in the power planning. It also explains the advantages on usage of renewable resources in the contrary to conventional resources. Chapter 2 details the modular smart grid inverters, conventional inverters which uses ordinary converters in the inverter system and the corresponding simulation description of the model. Chapter 3 describes the proposed system along with the control strategies of switching on between the inverters according to the load and also use of converters according to the available renewable resources. The MATLAB Simulation model of the proposed system is also obtained and compared with the base paper model in Chapter 4 .Chapter 5 deals with the hardware modelling of the proposed system results of hardware testing and the process coding of the PIC controller. In Chapter 6 the conclusion and future scope of the project is discussed.

CHAPTER 2

2. MODULAR DESIGN METHODOLOGY FOR SMART GRID INVERTERS

2.1 INVERTER DESIGN CHARACTERSTICS

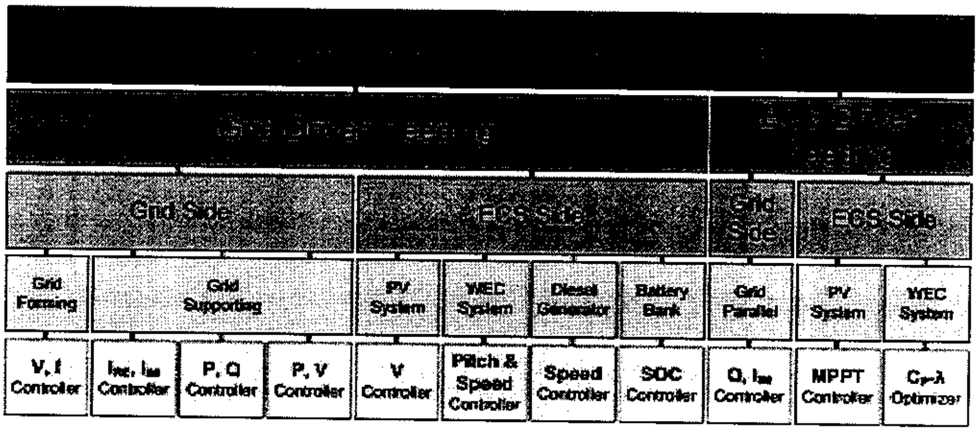
Inverters are the interfaces between ECS and grid or loads, the type and behaviour of these two systems on both inverter sides influence the inverter design. The characteristics can be basically described in

(i) Energy Conversion System Characteristics
(ii) Grid and Load Characteristics

2.1.1 Energy Conversion System Characteristics

Regarding the ECS or primary side of the inverter, a variety of sources is available; the different source characteristics individually have to be handled by the inverters. DC or AC sources have to be distinguished. DC sources are in example photovoltaic systems, batteries or fuel cells. Wind energy converters (WEC), flywheels and diesel generators on the other hand are AC sources. The different sources further more act as current or voltage sources. An additional ECS characteristic that has to be taken into account is the different current and voltage levels of ECS the inverter has to handle. For the operational mode of inverters, the type and behaviour of ECS is the main influencing. The operational mode is the deciding characteristic, mainly for the inverter control design. Generated energy of any RES should be utilized and fed to the grid when available. This operational mode is called the source or ECS drive feeding mode. Since conventional energy sources can deliver energy at any time, power injected to the grid can be set freely. If power of these sources is set by the grid as a power demand, this feeding mode is called load or grid driven feeding. Concerning energy storages like batteries or flywheel in control and management of power systems. This is mainly done by super ordinate control systems processing energy management and cost optimization. For different ECS systems' control, appropriate state and control variables are responsible for the intended operation of ECSs.

Table 1 Various feeding modes related to source



In Table 1, the mentioned source (ECS) related feeding modes are shown, extended by the corresponding ECS variables to be controlled.

2.1.2 Grid And Load Characteristics

On the grid or load side of the inverters also various different influencing characteristics have to be taken into account in inverter design. The main influencing characteristics are illustrated in Figure. 2.1. The first aspect of differentiation is whether the grid topology is an isolated or interconnected grid. The second noted characteristic the loads in the grid are passive or active. Passive grids only consume energy, while in active grids energy can also be fed to the grid by other sources. Beside the active or passive grid behaviour, also the symmetrical or asymmetrical characteristic of the load is influencing the inverter design.

The grid topology is the first influencing factor to the inverter control and feeding modes and at the grid side. In the mentioned grid-driven feeding mode, the grid-forming and grid-supporting mode can be differentiated. In case of an isolated grid as grid topology, the grid state variables, which are frequency and voltage, have to be built by the inverter itself (island operation). This mode is called grid forming mode. In most common cases, the grid topology is an interconnected grid where the inverter is connected to a highly meshed stiff grid including other generators. In this case the grid is defining the state variables, and the inverter has to adapt these variables. This operational mode of the inverter on the grid side is called grid supporting mode if the feeding mode is grid driven and grid parallel mode if the inverter feeding mode is ECS driven feeding. Also in case of changing grid situations, the fixed inverters not offering adaptability, may need to be replaced. An additional important functional requirement of inverters will be the ability to switch from a grid connected to an isolated operation,

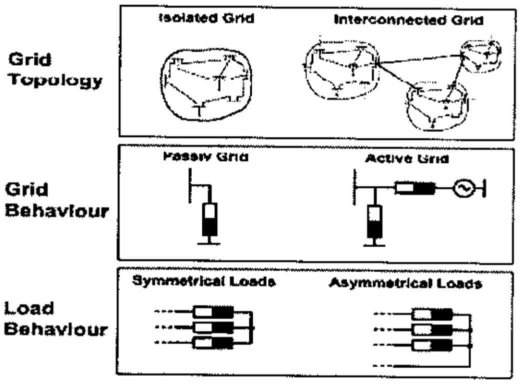


Figure 2.1 Feeding Modes on Inverter Sides

2.2 SIGNIFICANCE OF MODULAR INVERTERS

Conventional three phase inverter system structures are fixed in size and function and offer only limited flexibility demands and to be more versatile in production and development, a new standardized system concept with modular structure is needed. Modularity basically means a segmentation of the complex structures into functional groups. In this way the main components of an inverter structure can be subdivided and the resulting modules can be treated as stand alone systems. By use of standardized interfaces these separated modules can be scaled independently. The result is an inverter system that is completely adaptive regarding size, components, configuration and the operating control. The system is flexible to be quickly adapted and optimized for any application demands. Modularity or modular design is the subdivision of a complex system into smaller units (modules) with basic functionalities. These modules can then be used in different systems with multiple functionalities. Figure 2.2 shows the basic principle of modular design. A module pool keeps different discrete modules that can perform defined discrete tasks or functions. To connect any modules in a free selectable order and topology, standardized interfaces have to be defined to react on linked neighbour modules and hand over information to them. Production costs are reduced by completely independent manufacturing of the various modules. Furthermore, modular design offers additional benefits such as augmentation and exclusion. An existing system can be enlarged, updated, modified or pared down in functionality by adding or excluding new sub functional modules.

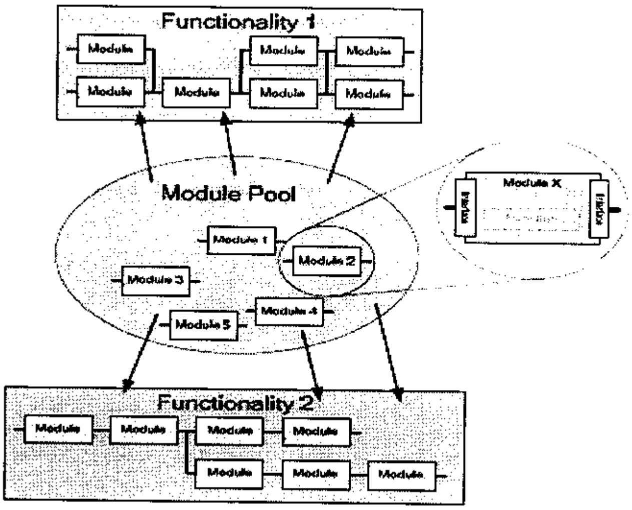


Figure 2.2 Basic Approach of Modularity

2.3 PRINCIPLE TO DESIGN MODULAR INVERTERS

The basic principle of modularity can be applied to the two main fields of inverter design, the hardware and the software design. Although these design fields are functional closely related to each other, they can be more or less decoupled in design by standardized interfaces or e.g. by the use of per unit (pu) or standardized values for communicated data. In the underlying project, the modular approach has been applied to the design of an exemplary inverter system .The applied modularity will now be detailed. At this point it has to be mentioned that the level and depth of modular design applied to inverters, but also to any other system, always depends on the product range of the manufacturer and the applications to be covered by the designed systems. The more complex a system is and the more functions it has to perform, the higher the level of modularity should be in the system.

The full advantages of the modular design can only be leveraged if the different target designs are based on equal components or if special explicit component groups are identified as common subject to failures, maintenance or upgrades. The modular design shown in this paper has to be considered as an example application of the modular inverter design approach. This example shows an inverter design which is able to handle nearly all desired functionalities of modern power systems. For higher power rating of the target inverter system, many of the existing modules can still be applied or multiples can be used in parallel.

The inverter is designed modular regarding its software and hardware elements. It can deal with any grid topology, grid behaviour, and load behaviour. It supports all control modes at the ECS and grid side and is able to handle all common ECSs.

2.3.1 Modular Inverter System Description

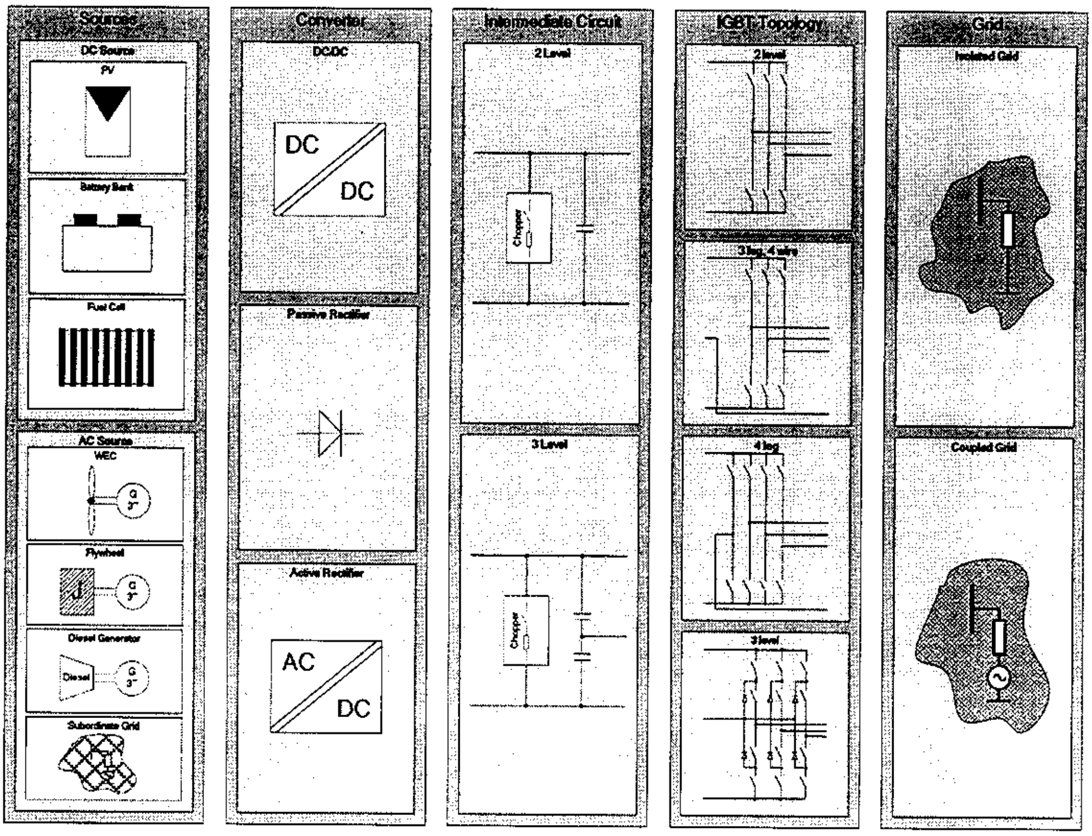


Figure 2.3 Modular Inverter Blocks

All basic inverter topologies are built of a couple of main functional elements. The selection and composition of these elements is mainly based on the type and behaviour of the ECS as well as the grid which the inverter is connected to. The basic components needed to operate any ECS and grid type are shown in Figure. 2.3. Three main module pools can be built. These are the converter, the intermediate circuit and the switch topology module pool. By selection of modules from these three module pools any typical basic inverter topology can be set up in hardware. The converter module pool itself contains DC/DC converters to adjust the voltage level of DC ECS to the intermediate circuit voltage and to actively control the DC sources. Passive and active rectifiers of this pool are able to connect AC sources to the intermediate circuit. The intermediate circuit pool keeps two different module types.

The circuits are the standard two level intermediate circuits built by one capacitor and the three level intermediate circuits with divide the intermediate circuit voltage in halves by the use of two series capacitors. The third wire in this case is connected to midpoint between the two capacitors. A chopper circuit is available for all intermediate circuit modules. It is closely linked to the intermediate circuit and will not be treated as separated module because of security aspects. The inverter topology for symmetrical loads is shown in Figure 2.4 This basic inverter is built of three IGBT legs. Each of the legs is generating the voltage for one grid phase by pulsing the intermediate circuit voltage. For asymmetrical loads two strategies are commonly applied. The three leg inverter with a neutral point ,Figure 2.5 is a combination of three single phase inverters sharing a common neutral line. The neutral line is connected to the mid-point of a common intermediate circuit built by two capacitors. These characteristics lead to different hardware topologies and also different control modes that have to be implemented regarding to the environment conditions of the inverter on its primary and secondary side.

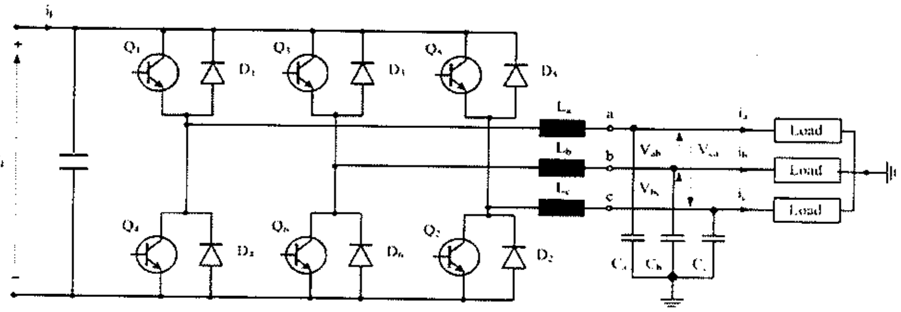


Figure 2.4 Three-leg Inverter

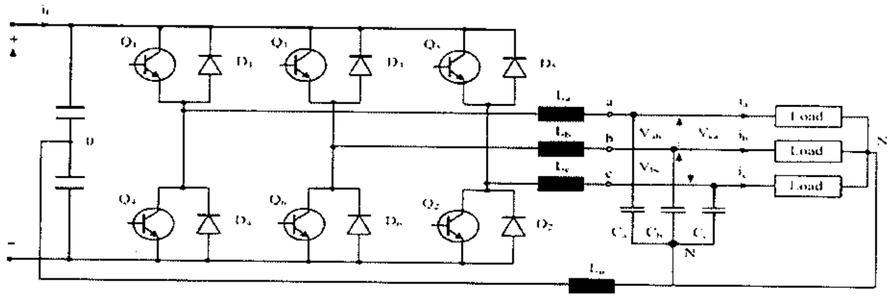


Figure 2.5 Three-leg Inverter with neutral point

2.3.2 Simulation Description

Inverter system was simulated using MATLAB/SIMULINK 7.5.The system was finally tested under common ECS and grid conditions and with different loads. The designed inverter is able to handle AC and DC sources as inputs. Symmetrical and asymmetrical load situations were successfully handled by application of three-leg, three leg four-wire IGBT bridge configurations. The intermediate circuit was adjusted to these different switch topologies. The presented example installation is a four-leg four-wire topology designed for a power rating of 10 kVA.

The test installation is set for a 3 phase system with a frequency of 50Hz. DC link voltage was 640 V, the applied switching frequency was 10 kHz, and the PWM output mode was symmetrical PWM. Balanced load with a resistance of 50 Ω at all phases. The inverter is operated in grid-forming mode at a voltage RMS value of 230V. A load step has been applied at ph"a" from 50 Ω to 25 Ω.

The inverter output voltages are a nearly undisturbed three phase signal in amplitude and phase while the current is increased in phase "a", due to the load step. In this case an unbalanced resistive-inductive load was placed. All phases were set to 50 Ω initially, while phase "a" includes a 3 mH inductance in series as well. An unsymmetrical load step from 50 Ω to 25 Ω in phase "a" was performed. The inverter maintained the three phase voltages and the unsymmetrical currents were driven in respect to the load step. The quick reaction of the modular inverter control to the load step can be seen.

2.3.2 Simulation Diagram & Results

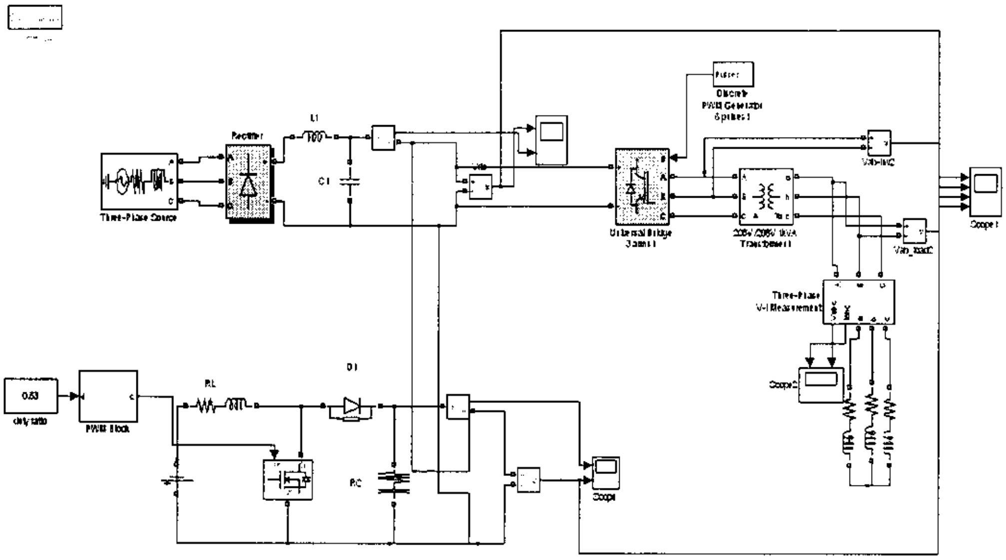


Figure 2.6 Inverter system with Symmetrical Load

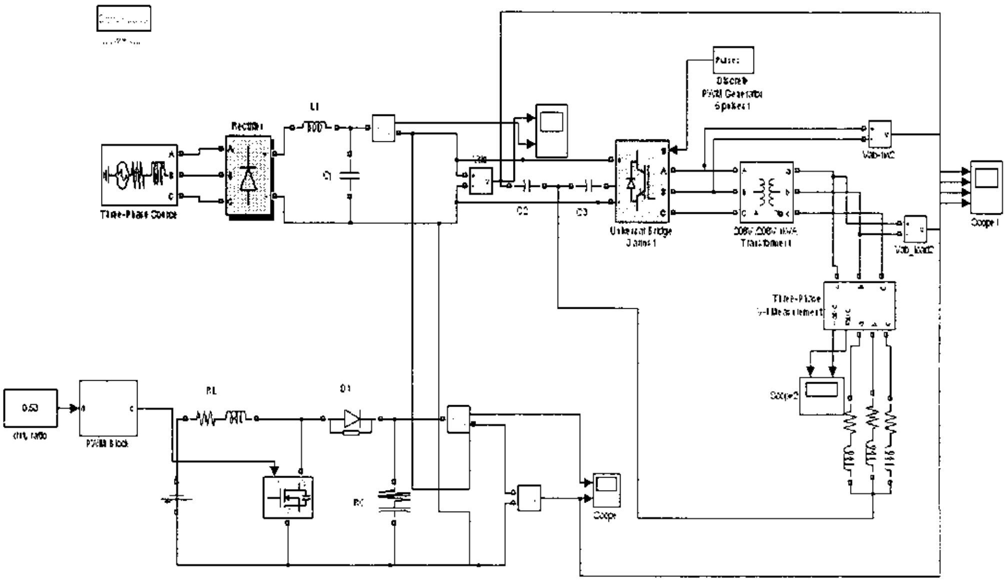


Figure 2.7 Inverter system with Asymmetrical Load

Modular Inverter With Symmetrical Load

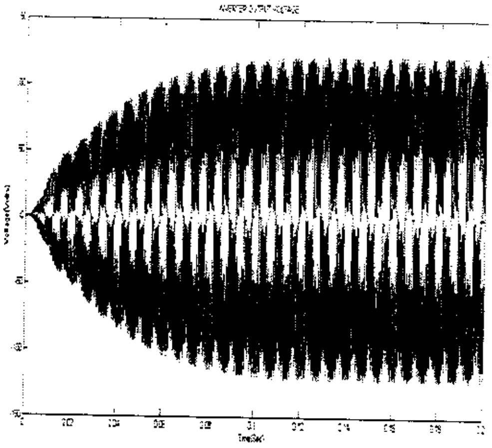


Figure 2.8 Inverter Output Voltage

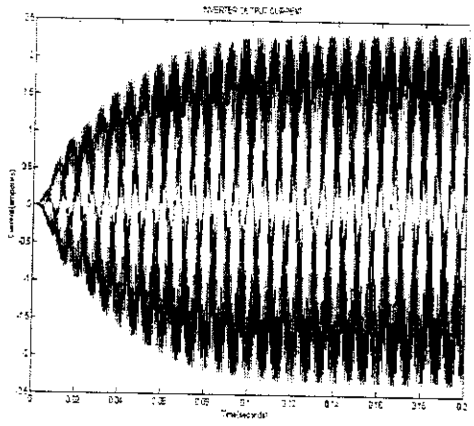


Figure 2.9 Inverter Output Current

Modular Inverter With Asymmetrical Load

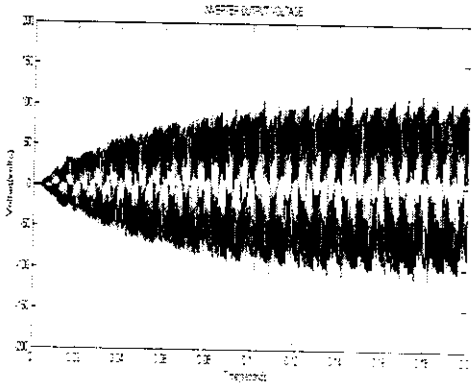


Figure 2.10 Inverter Output Voltage

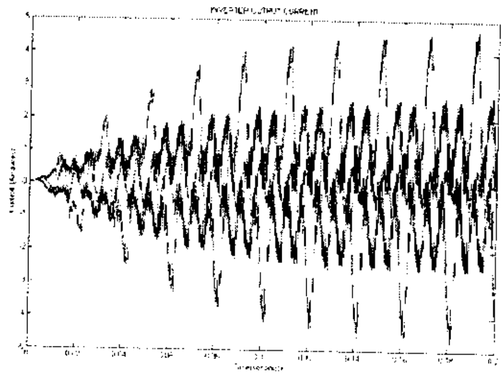


Figure 2.11 Inverter Output Current

2.4 DISCUSSION ON RESULTS

The Inverter system is designed in the paper such that it is capable of getting both AC and DC inputs from sources like PV cells, Fuel cells, Wind energy system etc, also the inverter is designed to handle two kinds of loads such as symmetrical and asymmetrical loads, Further the system is capable of handling in Grid feeding mode and Grid forming mode also. The Simulation is carried out for the modular Inverter system with symmetrical load and Asymmetrical load. DC source and AC source is given as input to the system such that n DC link a voltage of 650V is appeared. The Load is a three phase load with each branch handling a RL load of 50 Ohms and 3mH and the Inverter output voltage and Inverter output current is monitored for both symmetrical and asymmetrical load.

2.5 CONCLUSION

Three phase inverter systems are becoming a common architecture to connect energy converting systems and to form or support a grid. Conventionally available inverters are fixed in size and function and offer only limited flexibility. In this paper an advanced design strategy, the modular inverter design, is introduced. It enables faster reaction to demands and leads to a high level of flexibility in production and development, while also reducing costs. This modular design strategy has successfully been tested under various source and load conditions. The inverter components can be built as nearly independent modules. The result of the presented approach is a powerful inverter system that is completely adaptive regarding size, components, configuration and the operating control. The system is flexible to be quickly adapted and optimized for various applications. As further advantage, in case of any faults single defective modules can easily be replaced without long downtime. Modular inverter design therewith safes efforts and time in maintenance and repair. With the proposed design methodology, inverter systems can further be changed, rescaled, integrated and expanded easily by adding new functional groups. Any distributed sources can be easily integrated into the grid control strategy and contribute to supply stability. This makes the power supply structure more flexible, reliable and finally more cost-effective.

CHAPTER 3

3. A CUK-SEPIC BASED MODULAR INVERTER

3.1 CUK – SEPIC MULTI INPUT RECTIFIER

A system diagram of the proposed rectifier stage of hybrid energy system is shown in Figure. 2, where one of the inputs is connected to the output of the PV array and the other input connected to the output of a generator. The fusion of the two converters is achieved by reconfiguring the two existing diodes from each converter and the shared utilization of the Cuk output inductor by the SEPIC converter. This configuration allows each converter to operate normally individually in the event that one source is unavailable. Figure. 3 illustrate the case when only the wind source is available. In this case, $D1$ turns off and $D2$ turns on; the proposed circuit becomes a SEPIC converter and the input to output voltage relationship is given by (1). On the other hand, if only the PV source is available, then $D2$ turns off and $D1$ will always be on and the circuit becomes a Cuk converter as shown in Figure. 4. The input to output voltage relationship is given by (2). In both cases, both converters have step-up/down capability, which provide more design flexibility in the system if duty ratio control is utilized to perform MPPT control.

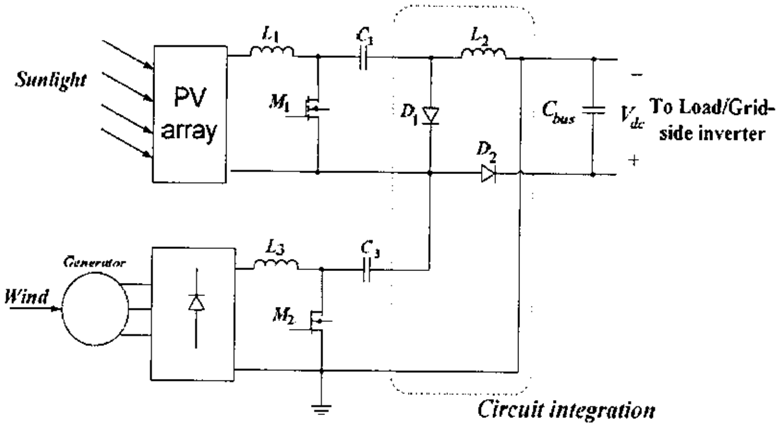


Figure 3.1 Cuk – Sepic Based Converter on Source side

3.2 SWITCHING STATES OF PROPOSED RECTIFIER

Figure 6 illustrates the various switching states of the proposed converter. If the turn on duration of *M1* is longer than *M2*, then the switching states will be state I, III. Similarly, the switching states will be state I, II, III if the switch conduction periods are vice versa. To provide a better explanation, the inductor current waveforms of each switching state are given as follows assuming that *d2* > *d1;* hence only states I, II, III are discussed in this example. In the following, *Ii,PV* is the average input current from the PV source; *Ii, W* is the RMS input current after the rectifier (wind case); and *Idc* is the average system output current. The key waveforms that illustrate the switching states in this example are shown in Figure.5, the mathematical expression that relates the total output voltage and the two input sources are shown below (11).

$$\frac{V_{dc}}{V_W} = \frac{d_2}{1-d_2} \qquad (1)$$

$$\frac{V_{dc}}{V_{PV}} = \frac{d_1}{1-d_1} \qquad (2)$$

State I (M_1 on, M_2 on)

$$i_{L1} = I_{i,PV} + \frac{V_{PV}}{L_1} t \qquad 0<t<d_1T_s \qquad (3)$$

$$i_{L2} = I_{dc} + \left(\frac{v_{c1} + v_{c2}}{L_2} \right) t \qquad 0<t<d_1T_s \qquad (4)$$

$$i_{L3} = I_{i,W} + \frac{V_W}{L_3} t \qquad 0<t<d_1T_s \qquad (5)$$

State II (M_1 off , M_2 on)

$$i_{L1} = I_{i,PV} + \left(\frac{V_{PV} - v_{c1}}{L_1} \right) t \qquad d_1T_s <t< d_2T_s \qquad (6)$$

$$i_{L2} = I_{dc} + \frac{v_{c2}}{L_2} t \qquad d_1T_s <t< d_2T_s \qquad (7)$$

$$i_{L3} = I_{L,W} + \frac{V_W}{L_3}t \qquad d_1T_s < t < d_2T_s \qquad (8)$$

State III (M_1 off , M_2 off)

$$i_{L1} = I_{L,PV} + \left(\frac{V_{PV} - v_{c1}}{L_1}\right)t \qquad d_2T_s < t < T_s \qquad (9)$$

$$i_{L2} = I_{dc} - \frac{V_{dc}}{L_2}t \qquad d_2T_s < t < T_s \qquad (10)$$

$$i_{L3} = I_{L,W} + \left(\frac{V_W - v_{c2} - V_{dc}}{L_3}\right)t \quad d_2T_s < t < T_s \qquad (11)$$

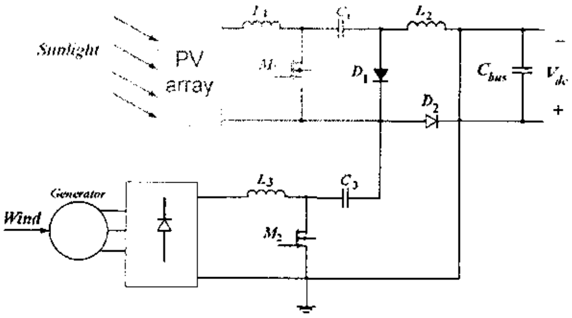


Figure 3.2 Sepic Converter (Wind source available)

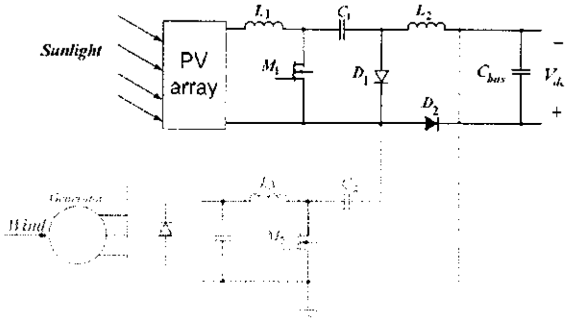


Figure 3.3 Cuk Converter (PV source available)

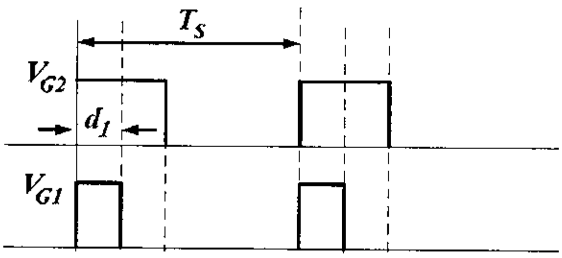


Figure 3.4 Switching Pulses V_{G2} & V_{G1}

$$V_{dc} = \left(\frac{d_1}{1-d_1}\right)v_{PV} + \left(\frac{d_2}{1-d_2}\right)v_W \qquad (12)$$

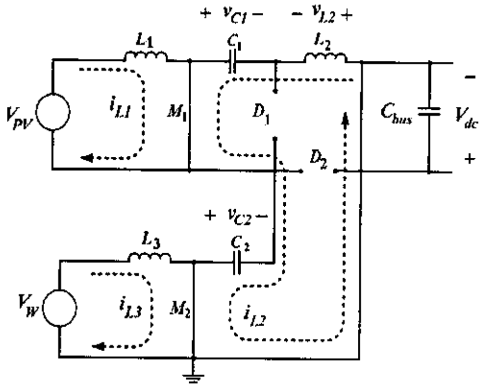


Figure 3.5 M1 ON, M2 ON

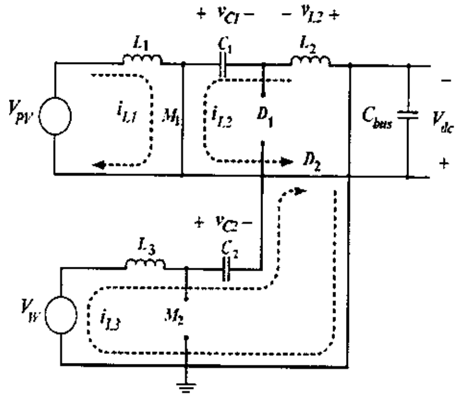


Figure 3.6 M1 ON, M2 OFF

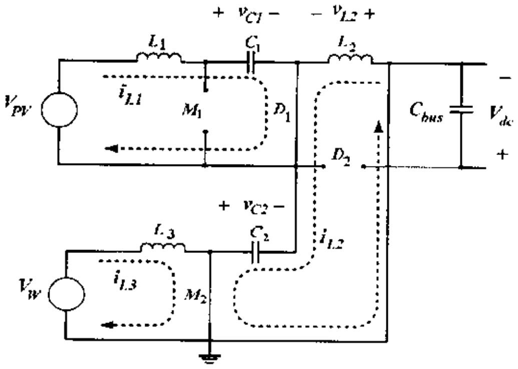


Figure 3.7 M1 OFF ,M2 ON

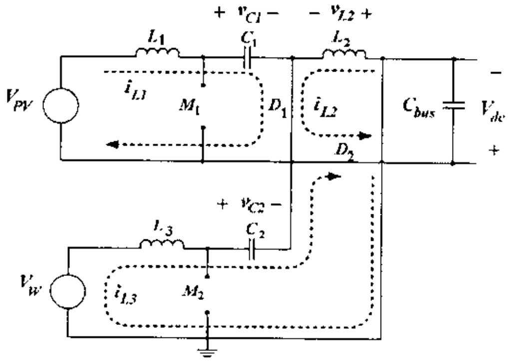


Figure 3.8 M1 OFF ,M2 OFF

3.3 DESIGN OF CUK - SEPIC BASED INVERTER

The basic principle of modularity can be applied to the two main fields of inverter design, the hardware and the software design. Although these design fields are functional closely related to each other, they can be more or less decoupled in design by standardized interfaces or e.g. by the use of per unit (pu) or standardized values for communicated data. In the underlying project, the modular approach has been applied to the design of an exemplary inverter system the applied modularity will now be detailed. At this point it has to be mentioned that the level and depth of modular design applied to inverters, but also to any other system, always depends on the product range of the manufacturer and the applications to be covered by the designed systems. The more complex a system is and the more functions it has to perform, the higher the level of modularity should be.

The characteristic of the inverter load regarding the symmetry is one of the main influencing factors of the desired power electronic inverter topology. The inverter topology for Symmetrical loads ,This basic inverter is built of three IGBT legs. Each of the legs is generating the voltage for one grid phase by pulsing the intermediate circuit voltage. For asymmetrical loads two strategies are commonly applied. The three leg inverter with a neutral point is a combination of three single phase inverters sharing a common neutral line. The neutral line is connected to the mid-point of a common intermediate circuit built by two capacitors These characteristics lead to different hardware topologies and also different control modes that have to be implemented regarding to the environment conditions of the inverter on its primary and secondary side. As stated in the introduction, most inverters are fixed in their power rating and functionality. Future inverters, however, need to be able to adapt changing source and load situations. The converter side of the inverter system two sources are available and it inputs to the two ways of the inverter module ,both from the cuk and sepic mode present in the converters. The system has main advantage as that it works on any one kind of the renewable resources or both kind if renewable resources, the Microcontroller is used in the inverter system for purposes such as for indication of the switching of loads, converter strategy and the working of PWM pulses to the inverter.

3.4 MODULAR INVERTER SPECFICATIONS

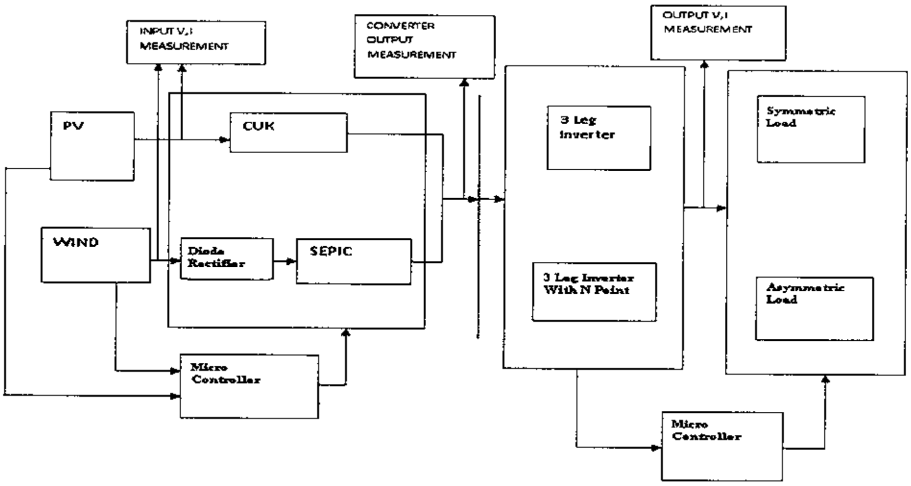


Figure 3.9 Modular Inverter Blocks

All basic inverter topologies are built of a couple of main functional elements. The selection and composition of these elements is mainly based on the type and behavior of the ECS as well as the grid which the inverter is connected to. The basic components needed to operate any ECS and grid type are shown in Figure 3. 9 .Three main module pools can be built. These are the converter, the intermediate circuit and the switch topology module pool. By selection of modules from these three module pools any typical basic inverter topology can be set up in hardware. The converter module pool itself contains DC/DC converters to adjust the voltage level of DC ECS to the intermediate circuit voltage and to actively control the DC sources. Passive and active rectifiers of this pool are able to connect AC sources to the intermediate circuit.

The intermediate circuit pool keeps two different module types the circuits are the standard two level intermediate circuits built by one capacitor and the three level intermediate circuits with divide the intermediate circuit voltage in halves by the use of two series capacitors. The third wire in this case is connected to midpoint between the two capacitors. A chopper circuit is available for all intermediate circuit modules. It is closely linked to the intermediate circuit and will not be treated as separated module because of security aspects.. The inverter topology for symmetrical loads is this basic inverter is built of three IGBT legs either three leg inverter or three leg inverter with neutral point.

CHAPTER 4

SIMULATION OF THE SMART GRID INVERTER USING MATLAB

4.1 MATLAB

The name MATLAB stands for matrix laboratory. MATLAB is a high-performance language for technical computing. It Integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation . In this project the modelling and simulation of the proposed system is done using MATLAB (using simulink and power system block set tool boxes).

SIMULINK

Simulink is a software package for modelling, simulating, and analyzing non linear dynamical systems. It is a graphical mouse-driven program that allows somebody to model a system by drawing a block diagram on the screen and manipulating it dynamically. Simulink is a platform for multi domain simulation and Model-Based Design for dynamic systems. It provides an interactive graphical environment and a customizable set of block libraries, and can be extended for specialized applications.

POWER SYSTEM BLOCK SET

The Power System Block set allows scientists and engineers to build models that simulate power systems. The block set uses the Simulink environment, allowing a model to be built using click and drag procedures. Not only can the circuit topology be drawn rapidly, but also the analysis of the circuit can include its interactions with mechanical, thermal, control, and other disciplines. Sim Power Systems extends Simulink with tools for modelling and simulating basic electrical circuits and detailed electrical power systems. These tools let you model the generation, transmission, distribution, and consumption of electrical power, as well as its conversion into mechanical power. Sim Power Systems is well suited to the development of complex, self-contained power systems, such as those in automobiles, aircraft, manufacturing plants, and power utility applications

4.2 DESIGN IMPLICATIONS ON CONVERTER SIDE

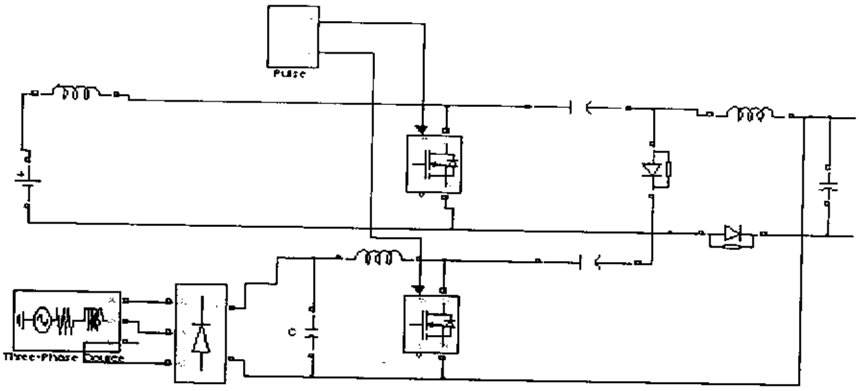


Figure 4.1 Simulation circuit for Cuk- Sepic based converter

The design implication of the converter includes two kinds of boost converters , cuk and sepic type of converters ,it is a new configuration of the front-end rectifier stage for a hybrid wind/photovoltaic energy system. This configuration allows the two sources to supply the load separately or simultaneously depending on the availability of the energy sources. The inherent nature of this Cuk-SEPIC fused converter, additional input filters are not necessary to filter out high frequency harmonics. Harmonic content is detrimental for the generator lifespan, heating issues, and efficiency. The fused multi input rectifier stage also allows Maximum Power Point Tracking (MPPT) to be used to extract maximum power from the wind and sun when it is available. A system diagram of the proposed rectifier stage of a hybrid energy system is shown in Figure 4.1, where one of the inputs is connected to the output of the PV array and the other input connected to the output of a generator.

The fusion of the two converters is achieved by reconfiguring the two existing diodes from each converter and the shared utilization of the Cuk output inductor by the SEPIC converter.

The Converter circuit provides the operation which illustrates the case when only the wind source is available. In this case, *D*1 turns off and *D*2 turns on; the proposed circuit becomes a SEPIC converter . On the other hand, if only the PV source is available, then *D*2 turns off and *D*1 will always be on and the circuit becomes a Cuk converter . In both cases, both converters have step-up/down capability.

4.2.1 Converter Switching Strategy

The converter switching is managed through the two switches M1 and M2 present on the converters by effectively commutating the circuit current is bypassed into the load and the circuit is held at a constant value with the help of the pulses in accordance with the switching states. The switching states include four levels of switching they are

- M1 ON , M2 ON
- M1 ON , M2 OFF
- M1 OFF, M2 ON
- M1 OFF, M2 OFF

In accordance with the switching states the Inductor and switching waveforms are given as,

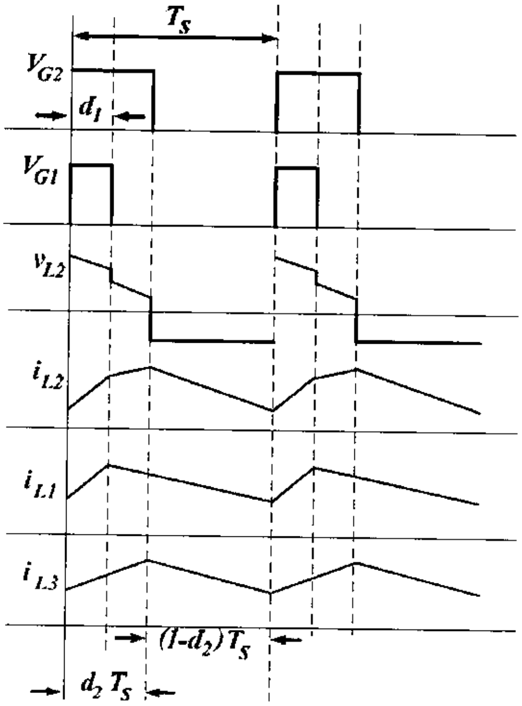


Figure 4.2 Waveforms of Switching states

$$V_{dc} = \left(\frac{d_1}{1-d_1}\right)v_{PV} + \left(\frac{d_2}{1-d_2}\right)v_{Br}$$

From the equation *Vdc* is simply the sum of the two output voltages of the Cuk and SEPIC converter. This further implies that *Vdc* can be controlled by *d*1 and *d*2 individually or simultaneously.

4.3 DESIGN IMPLICATIONS ON INVERTER SIDE

All basic inverter topologies are built of a couple of main functional elements. The selection and composition of these elements is mainly based on the type and behavior of the ECS as well as the grid which the inverter is connected to. The basic components needed to operate any ECS and grid. Three main module pools can be built. These are the converter, the intermediate circuit and the switch topology module pool. By selection of modules from these three module pools any typical basic inverter topology can be set up in hardware. The converter module pool itself contains DC/DC converters to adjust the voltage level of DC ECS to the intermediate circuit voltage and to actively control the DC sources. Passive and active rectifiers of this pool are able to connect AC Sources to the intermediate circuit.

The intermediate circuit pool keeps two different module types. These are the standard two level intermediate circuits built by one capacitor and the three level intermediate circuits with divide the intermediate circuit voltage in halves by the use of two series capacitors. The third wire in this case is connected to midpoint between the two capacitors. A chopper circuit is available for all intermediate circuit modules. It is closely linked to the intermediate circuit and will not be treated as separated module because of security aspects. The switch topology module pool (grid side) consists of different IGBT bridge topologies. These are the two level topology for Symmetrical loads, the three leg four wire and the four leg topology for asymmetrical loads, and e.g. The advanced three level topology. With these modules connected by standardized interfaces and the corresponding control and management environment, any inverter functionality can be composed.

The symmetrical load is taken to be as o standard RL type load which can be seen in any grids available and asymmetrical loads are differentiated from the symmetrical loads by the value of the various impedance value present on the legs of the load, as in a 50hz system the differentiation is shown here by changing the middle leg value of the impedance present in the system .

4.3.1 Inverter Switching Control

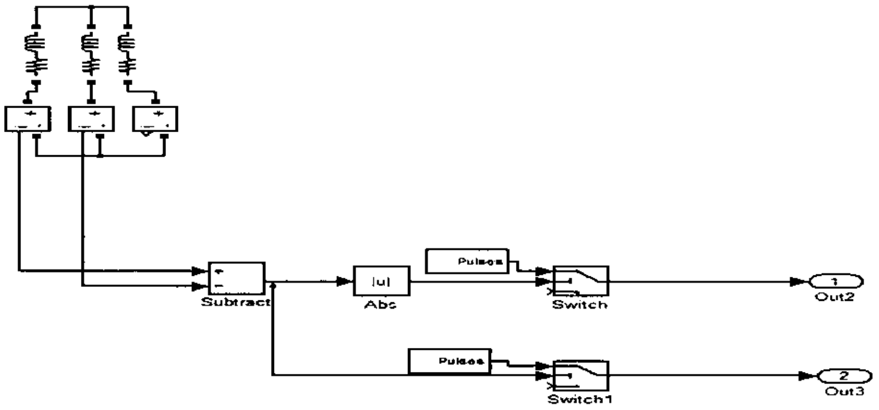


Figure 4.3 Inverter Switching Circuitry

The Inverter is switched on from according to the loads like symmetrical and asymmetrical by comparing the currents from three phase load branch circuits and by putting suitably a comparator to compare the currents in the branches and if the currents in the individual branches are equal the load corresponds to symmetrical and if the current differs the load is asymmetrical, practically the switching is achieved by controlling the pulses over the particular IGBT's of the corresponding Inverters. Here as shown in Figure 4.3 the load is taken as RL and the current on the individual leg is compared and taken absolute values then taken pulses to the individual inverter are controlled.

4.4 SIMULATION DESCRIPTION AND DIAGRAM

Inverter system was simulated using MATLAB/SIMULINK .The system was finally tested under common ECS and grid conditions and with different loads. The designed inverter is able to handle AC and DC sources as inputs. Symmetrical and asymmetrical load situations were successfully handled by application of three-leg, three leg four-wire IGBT bridge configurations. The intermediate circuit was adjusted to these different switch topologies.

The test installation is set for a 3 phase system with a frequency of 50Hz. the applied switching frequency was 10 kHz, the PWM output mode was symmetrical PWM. Balanced load with a resistance of 50 Ω at all phases. The inverter output voltages are a nearly undisturbed three phase signal in amplitude and phase while the current is increased in phase "a", due to the load step. In this case an unbalanced resistive-inductive load was placed. All phases were set to 50 Ω initially, while phase "a" includes a 3 mH inductance in series as well. An unsymmetrical load step from 50 Ω to 25 Ω in phase "a" was performed. The quick reaction of the modular inverter control to the load step can be seen.

In the converter side of the Modular inverter system the Cuk and Sepic converters are modelled in Simulink and instead of a wind source a three phase AC supply is provided to it and instead of the PV array modelling a standard DC source is modelled with it to the system, the system controller is a standard controller for the Loads switching inverter controlling the PWM pulses to the system. The output are measured in various system parts

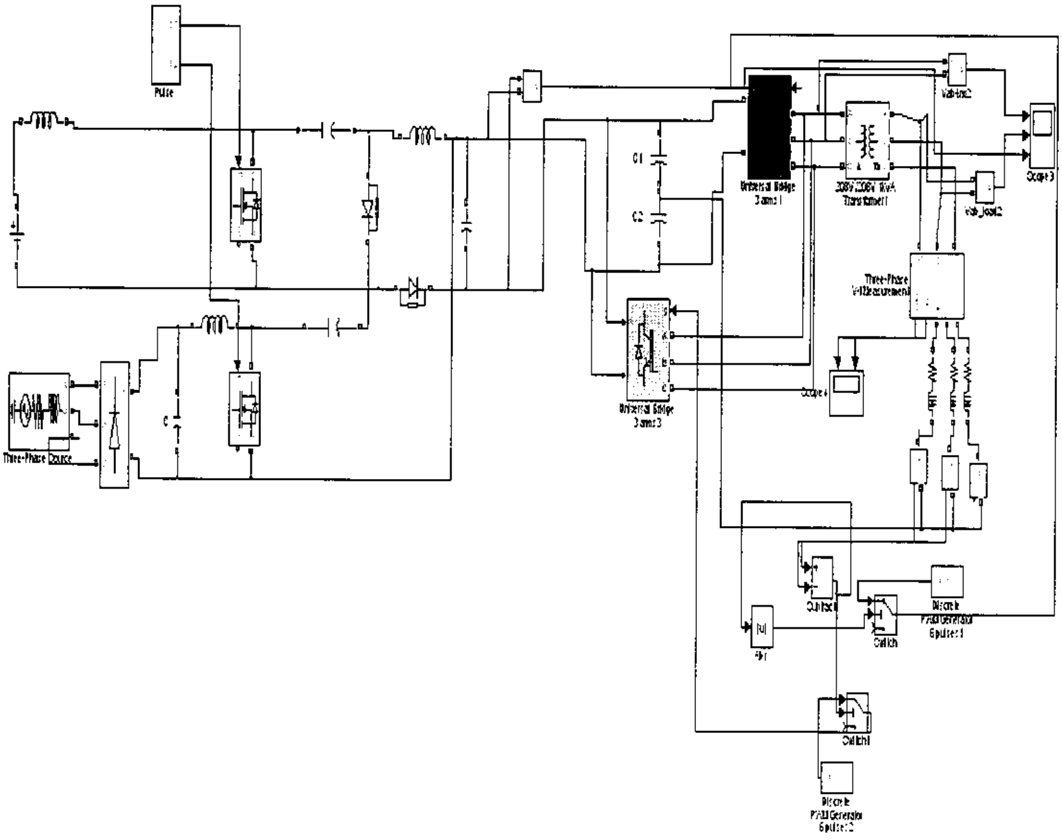


Figure 4.4 Simulink Model of the proposed Modular Inverter System

4.5 SIMULATION RESULTS

4.5.1 Modular Inverter With Symmetrical Load

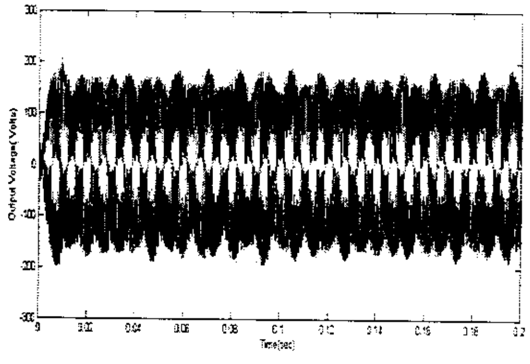


Figure 4.5 Inverter Output voltage

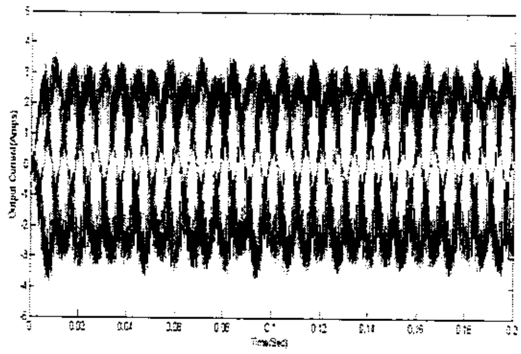


Figure 4.6 Inverter Output Current

4.5.2 Modular Inverter With Asymmetrical Load

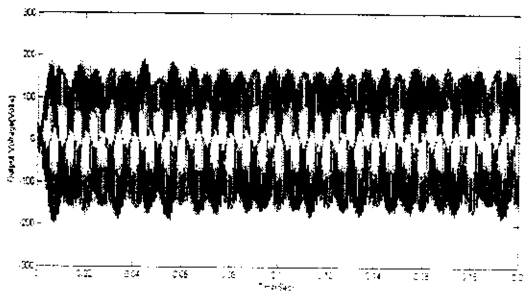


Figure 4.7 Inverter Output voltage

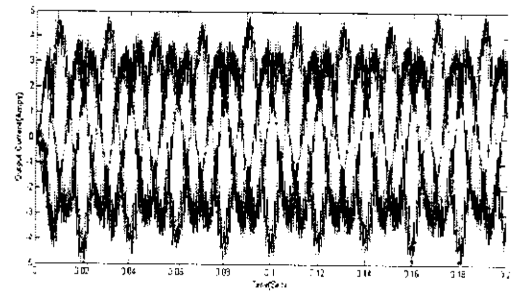


Figure 4.8 Inverter Output Current

4.5.3 Converter Switching Waveforms

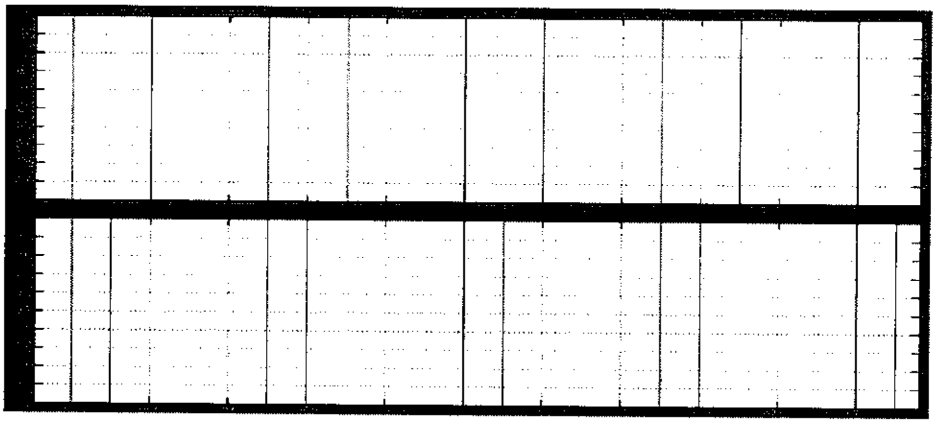


Figure 4.9 Switching Pulses V_{G2} & V_{G1}

4.5.4 THD Comparisons of Existing And Proposed System

Existing System

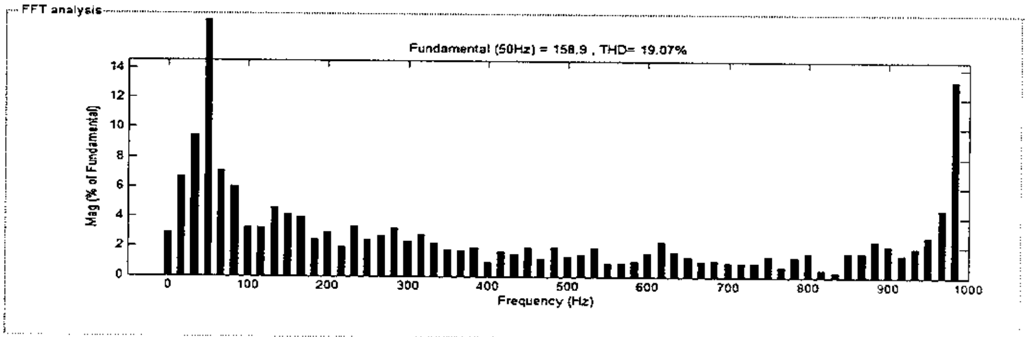


Figure 4.10 Existing system's THD diagram

Proposed System

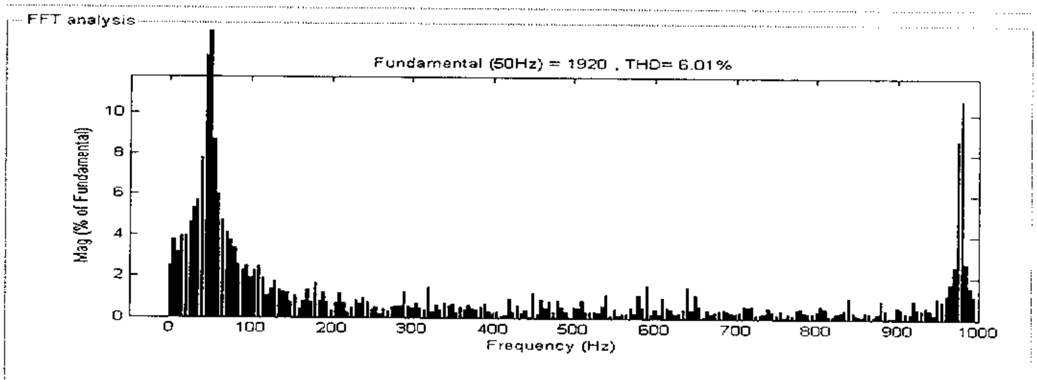


Figure 4.11 Proposed systems' THD diagram

CHAPTER 5

5. HARDWARE MODEL OF THE PROPOSED SYSTEM

5.1 SCHEMATIC DIAGRAM OF PROPOSED SYSTEM

The prototype model of the proposed system, consists of two important blocks Inverter system and converter system Figure 5.1, shows the converter blocks consists of two basic kinds of boost DC to DC converters Cuk and Sepic in accordance with the switching the converter supplies power. Similarly Figure 5.2, shows the schematic diagram of Inverters switching.

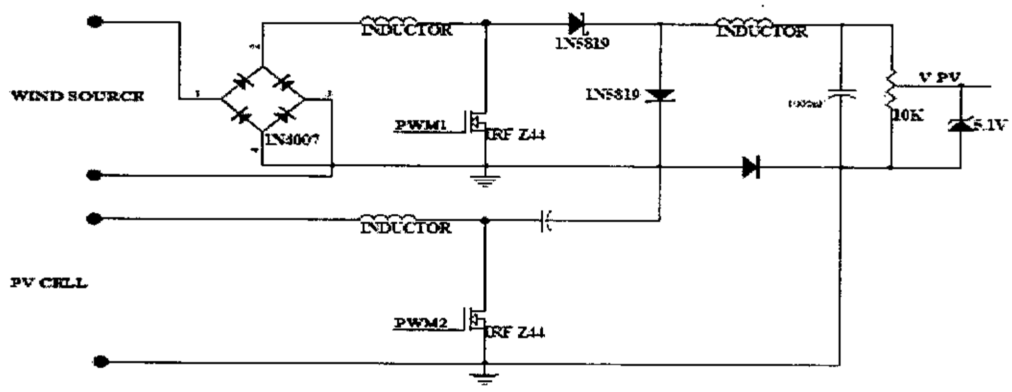


Figure 5.1 Schematic diagram of converters

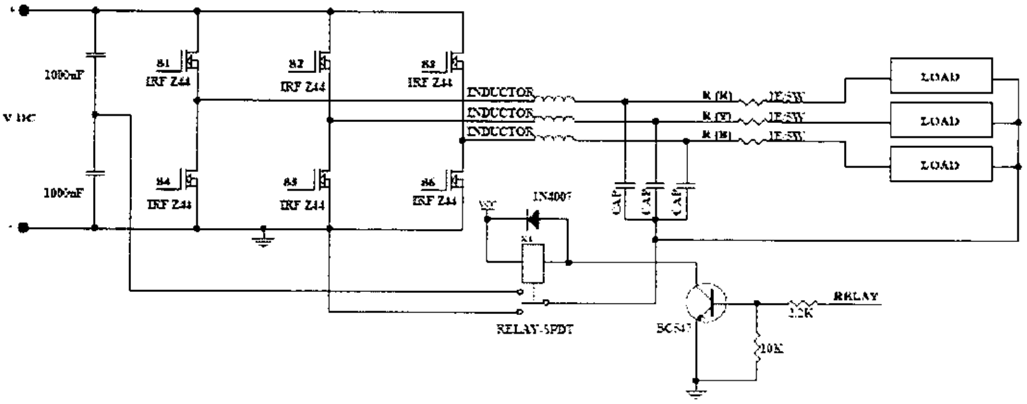


Figure 5.2 Schematic diagram of Inverter Load and Switching Circuits

5.2 SCHEMATIC DIAGRAM OF DUAL POWER SUPPLY UNIT

The rectifier block contains a step down transformer, which step downs the input voltage from 220V to 12V. In addition, the step downed voltage is rectified to DC. This is done by uncontrolled single phase diode rectifier. The output of this block is 12V dc. Then this 12V dc is stepped down into 5V and is given to the PIC microcontroller.

POWER SUPPLY

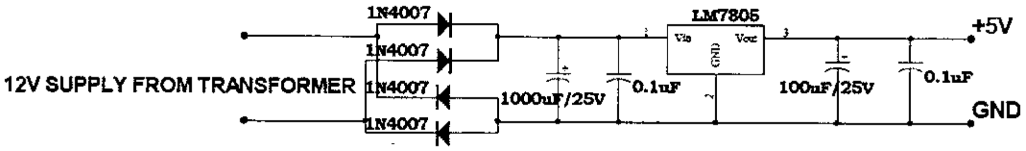


Figure.5.3 schematic of dual power supply unit

5.3 SHEMATIC OF MICROCONTROLLER

The schematic diagram of PIC microcontroller is shown in Figure.6.6. The gate pulse for the 6 switches of the matrix converter is generated by PIC16F877 controller. This micro controller circuit works in 5V power supply. So separate step down rectifier unit is made for the controller. The detail about PIC16F877A is given in APPENDIX I. This controller is isolated from the main circuits by means of opto-coupler.

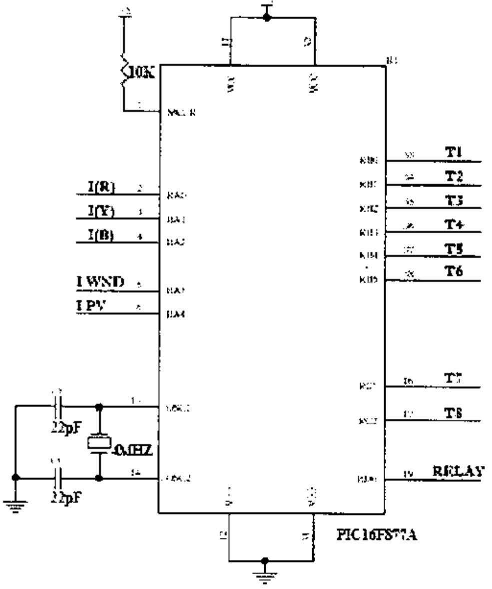


Figure 5.4 Schematic of PIC16F877A

5.3.1 Features of PIC16f877A

High-Performance RISC CPU

- Only 35 single word instructions to learn
- All instructions are 1µs (@4MHz) except for program branches which are 2 cycles
- Operating speed: DC - 20MHz clock input.

Peripheral Features:

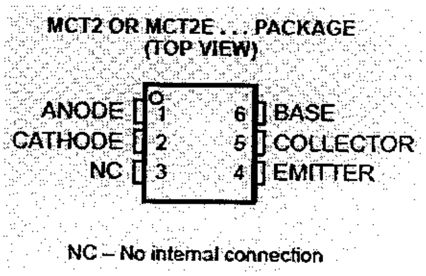
- Two 8-bit timer/counter (TMR0, TMR2) with 8-bit programmable prescaler.
- 12.5 ns resolution for PWM mode.
- Two Capture/Compare PWM (CCP) Modules.
- Brown-out detection circuitry for brown-out Reset (BOR).

Special Micro controller Features

- Power-On Reset
- Power-up Timer (PWRT) and Oscillator Start-Up Timer (OST)
- Selectable oscillator options.
- Watchdog timer (WDT) with its own on-chip RC oscillator for reliable operation.
- Self-reprogrammable under software control.
- Power saving Sleep mode.

5.4 OPTOCOUPLER

Optocoupler is also termed as optoisolator, Optoisolator a device which contains a optical emitter, such as an LED, neon bulb, or incandescent bulb, and an optical receiving element, such as a resistor that changes resistance with variations in light intensity, or a transistor, diode, or other device that conducts differently when in the presence of light. These devices are used to isolate the control voltage from the controlled circuit.



NC – No internal connection

Figure.5.5 Optocoupler

- Gallium Arsenide Diode Infrared Source Optically Coupled to a Silicon npn Phototransistor
- High Direct-Current Transfer Ratio
- Base Lead Provided for Conventional Transistor Biasing
- High-Voltage Electrical Isolation . . .
- 1.5-kV, or 3.55-kV Rating
- Plastic Dual-In-Line Package
- High-Speed Switching:

5.5 HARDWARE TESTING AND RESULTS

The fabricated hardware model is as shown in figure.5.6. The output waveforms of the proposed inverter system with voltage and current are shown in figure 5.7 and 5.8 respectively. The Cuk – Sepic based converter are switched according to the waveform shown in the figure 5.9. An average value of 24 V is maintained in the system. The four main parts of the modular inverter system are,

(i) Dual Supply unit (DC & AC)

(ii) Cuk – Sepic based converter circuits

(iii) Inverters (Three phase & Three phase with neutral point)\

(iv) Controller

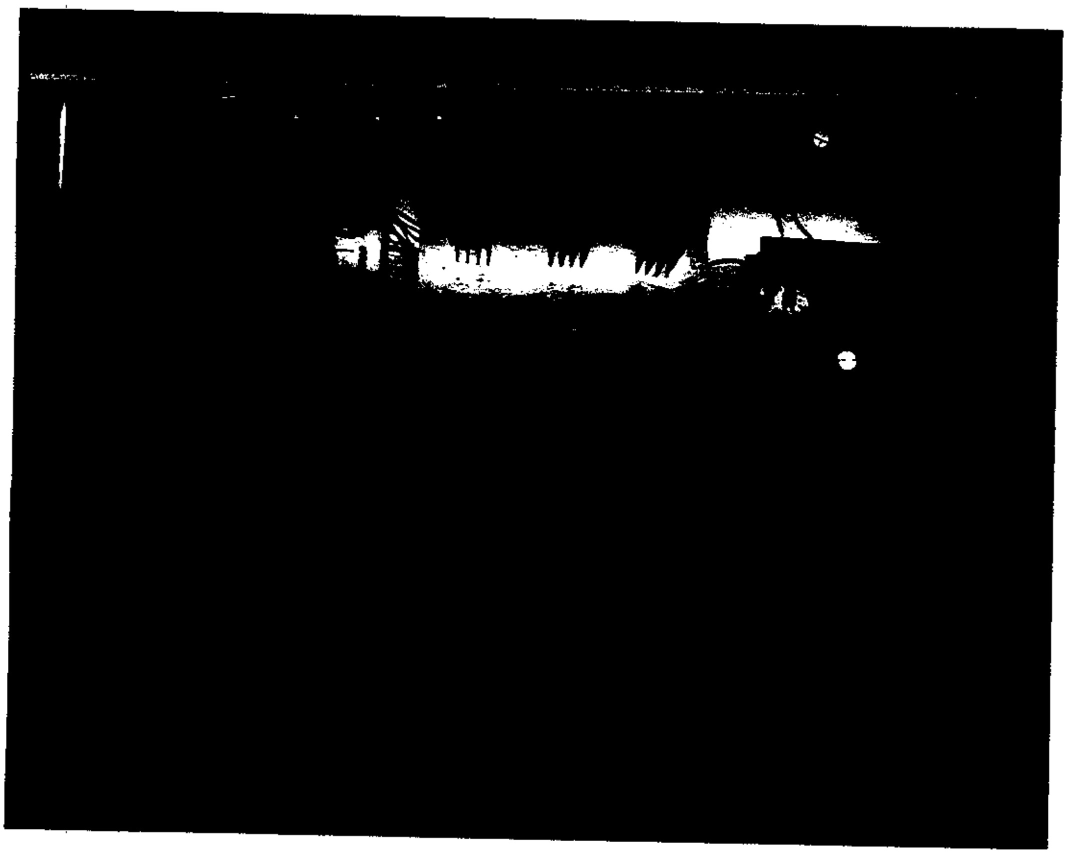


Figure.5.6 Hardware photography of proposed System

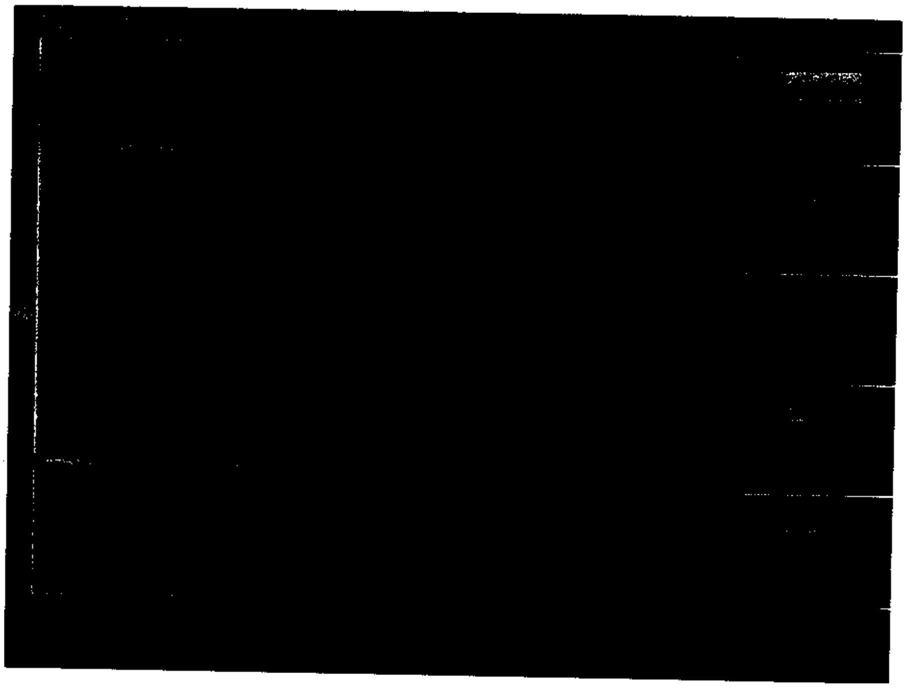


Figure.5.7 Output voltage of Inverter

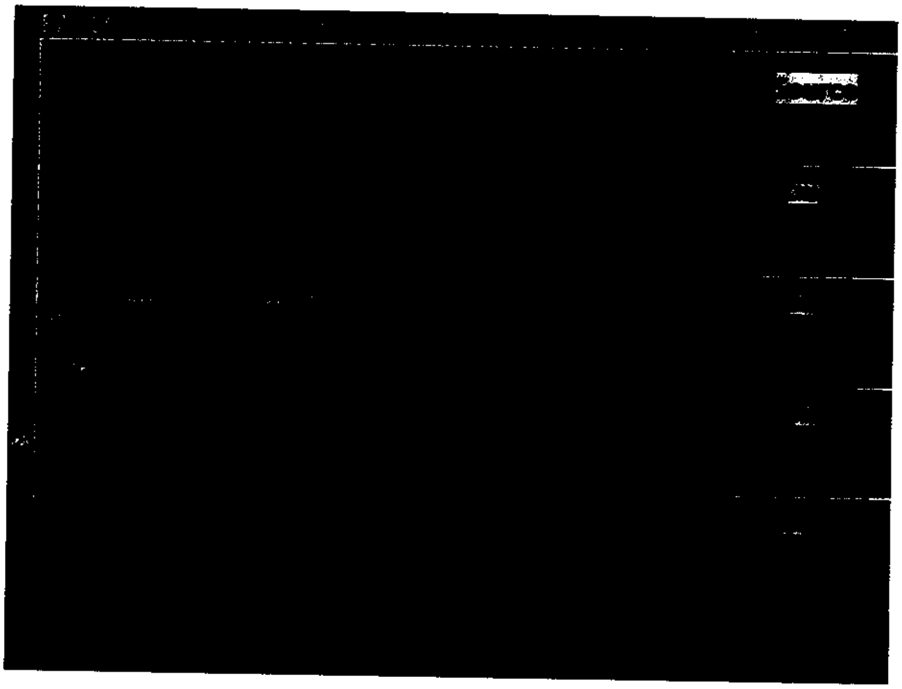


Figure.5.8 Output current of Inverter

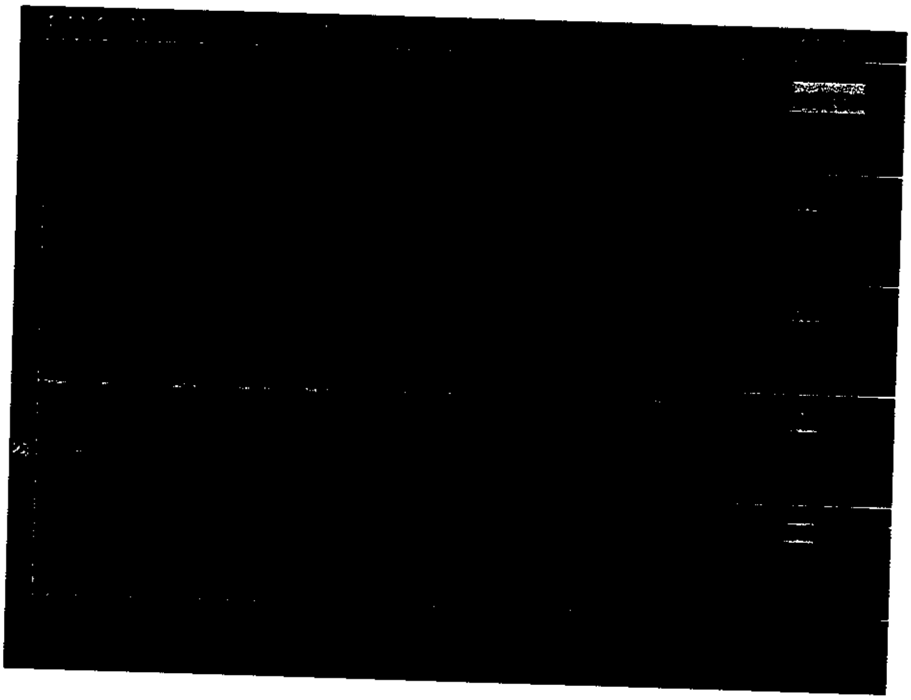


Figure.5.9 Switching waveforms on converter side

CHAPTER 6

\

6.CONCLUSION AND FUTURESCOPE

This modular design strategy has successfully been tested under various source and load conditions. The result of the presented approach is a powerful inverter system that is completely adaptive regarding size, components, configuration and the operating control. The system is flexible to be quickly adapted and optimized for various applications. In case of any faults single defective modules can easily be replaced without long downtime. Modular inverter design therewith safes efforts and time in maintenance and repair. A new multi-input Cuk-SEPIC rectifier stage additional input filters are not necessary to filter out high frequency harmonics one of the mail advantage of the system is that both renewable sources can be stepped up/down (supports wide ranges of PV and wind input), By the comparison of THD it is clear that the harmonics is greatly reduced in the proposed system and it is been reduced effectively. Modular inverter design therewith safes efforts and time in maintenance and repair.

MPPT can be realized for each source; individual and simultaneous operation is supported. Simulation results have been presented to verify the features of the proposed topology. With the proposed design methodology, inverter systems can further be changed, rescaled, integrated and expanded easily by adding new functional groups. Real time monitoring can be done in the system by connecting a Personal computer to the system for tracking various data's and to monitor the system effectively.

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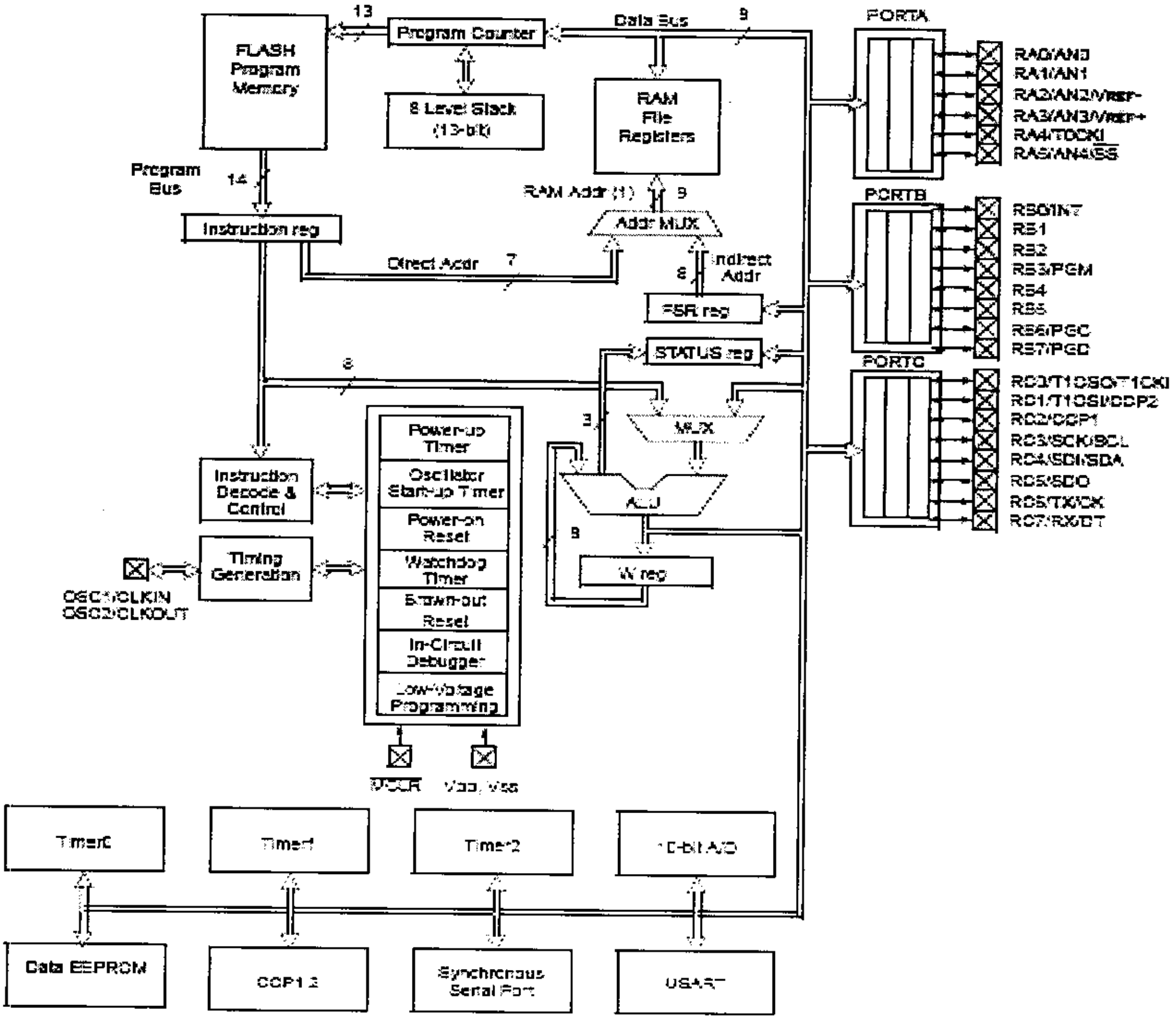
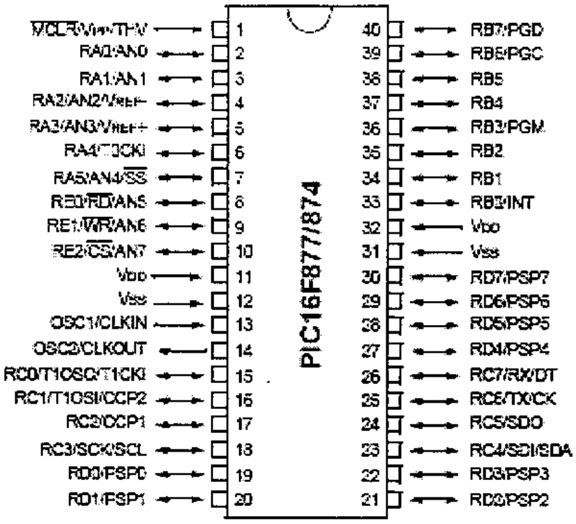
APPENDIX

ARCHITECTURE OF PIC 16F877A

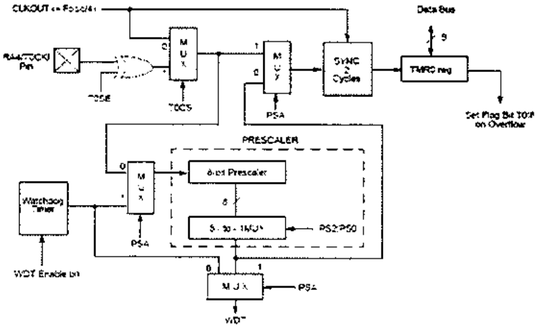
Device	Program FLASH	Data Memory	Data EEPROM
PIC16F873	4K	192 Bytes	128 Bytes
PIC16F876	8K	368 Bytes	256 Bytes



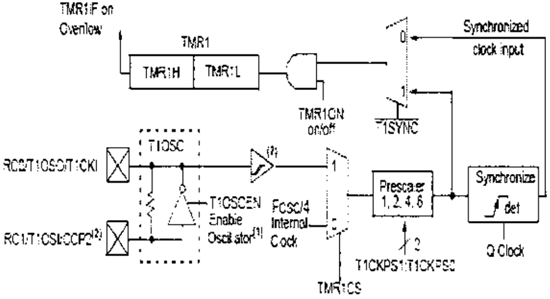
PIN CONFIGURATION OF PIC16F877A



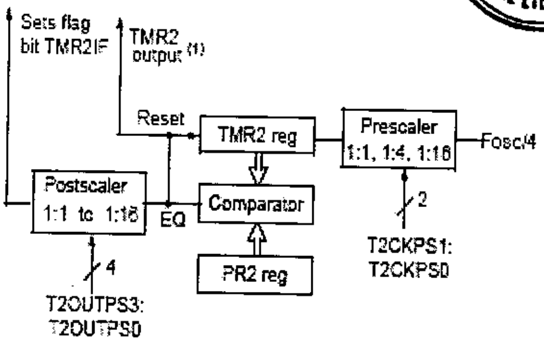
TIMERS 0 BLOCK DIAGRAM:



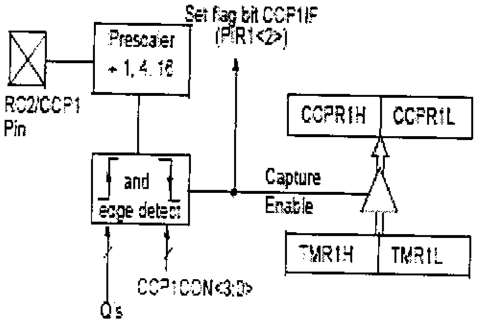
TIMER 1 BLOCK DIAGRAM:



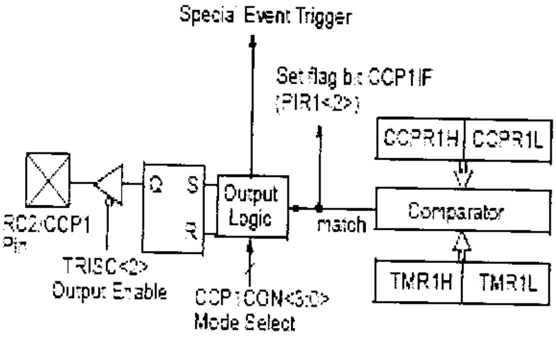
TIMER2 BLOCK DIAGRAM:



CAPTURE MODE OPERATION BLOCK DIAGRAM:



COMPARE MODE OPERATION BLOCK DIAGRAM:



FEATURES OF PIC:

- High-performance RISC CPU
- Only 35 single word instructions to learn
- Operating speed: DC - 20 MHz clock input
- DC - 200 ns instruction cycle
- Up to 8K x 14 words of Flash Program Memory,
- Up to 368 x 8 bytes of Data Memory (RAM)
- Up to 256 x 8 bytes of EEPROM data memory
- Interrupt capability (up to 14 internal/external)
- Eight level deep hardware stack
- Direct, indirect, and relative addressing modes
- Power-on Reset (POR)
- Power-up Timer (PWRT) and Oscillator Start-up Timer (OST)
- Watchdog Timer (WDT) with its own on-chip RC Oscillator for reliable operation
- Programmable code-protection
- Power saving SLEEP mode
- Selectable oscillator options
- In-Circuit Serial Programming (ICSP) via two pins
- Only single 5V source needed for programming capability
- In-Circuit Debugging via two pins
- Wide operating voltage range: 2.5V to 5.5V
- High Sink/Source Current: 25 mA
- Commercial and Industrial temperature ranges
- Low-power consumption:< 2 mA typical @ 5V, 4 MHz,20mA typical @ 3V, 32kHz < 1mA typical standby current

PIC PROGRAMMING

```
#include<pic.h>

__CONFIG(0X20E4);

__CONFIG(0X3FFF);

#define S1 RB0

#define S2 RB1

#define S3 RB2

#define S4 RB3

#define SW RB5

unsigned int REFF1,INPUT1,REFF2,INPUT2;

unsigned char count;

delay(void);

delay1(void);

void main()

{

        TRISC=0;

        PORTC=0;

        TRISB=0;

        PORTB=0;
```

```
 TRISA=0XFF;

 RC2=1;

 ANSEL=0X0F;

 ANSELH=0;

 ADCON1=0X80;

 PR2=99;

 T2CON=0X04;

 CCP1CON=0X0C;

 CCPR1L=75;

  CCP2CON=0X0C;

 CCPR2L=75;

 T1CON=0X01;

 TMR1L=0XF0;

 TMR1H=0XD8;

 GIE=PEIE=TMR1IE=1;

 while(1)

 {

/****************** ADC SCAN *****************/

        ADCON0=0X81;

        delay();
```

```
GODONE=1;
while(GODONE);
REFF1=(ADRESH*256)+ADRESL;
 ADCON0=0X85;
delay();
GODONE=1;
while(GODONE);
INPUT1=(ADRESH*256)+ADRESL;
ADCON0=0X89;
delay();
GODONE=1;
while(GODONE);
REFF2=(ADRESH*256)+ADRESL;
 ADCON0=0X8D;
delay();
GODONE=1;
while(GODONE);
INPUT2=(ADRESH*256)+ADRESL;
 PORTB=0x42;
while(TMR0<4);
```

```
PORTB=0x52;

while(TMR0<22);

PORTB=0x50;

while(TMR0<26);

PORTB=0x30;

while(TMR0<30);


PORTB=0x38;

while(TMR0<48);

PORTB=0x28;

while(TMR0<52);


PORTB=0x0C;

while(TMR0<56);

PORTB=0x0E;

while(TMR0<74);


PORTB=0x06;

while(TMR0<78);

TMR0=0;
```

```
PORTB=0x42;
while(TMR0<8);
PORTB=0x52;
while(TMR0<44);
PORTB=0x50;
while(TMR0<52);
PORTB=0x30;
while(TMR0<60);
PORTB=0x38;
while(TMR0<96);
PORTB=0x28;
while(TMR0<104);
PORTB=0x0C;
while(TMR0<112);
PORTB=0x0E;
while(TMR0<148);
PORTB=0x06;
while(TMR0<156);
TMR0=0;
```

```
        }


}


delay()


{

        unsigned int i;

        for(i=0;i<100;i++);

}

delay1()

{

        unsigned int j;

        for(j=0;j<10000;j++);

}
```

Advanced Power MOSFET IRFZ44

FEATURES

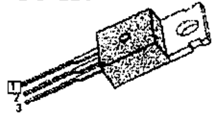
- Avalanche Rugged Technology
- Rugged Gate Oxide Technology
- Lower Input Capacitance
- Improved Gate Charge
- Extended Safe Operating Area
- 175°C Operating Temperature
- Lower Leakage Current: 10μA (Max.) @ V_{DS} = 60V
- Lower $R_{DS(ON)}$: 0.020Ω (Typ.)

BV_{DSS} = 60 V

$R_{DS(on)}$ = 0.024Ω

I_D = 50 A

TO-220



1.Gate 2. Drain 3. Source

Absolute Maximum Ratings

Symbol	Characteristic	Value	Units
V_{DSS}	Drain-to-Source Voltage	60	V
I_D	Continuous Drain Current (T_C=25°C)	50	A
	Continuous Drain Current (T_C=100°C)	35.4	
I_{DM}	Drain Current-Pulsed (1)	200	A
V_{GS}	Gate-to-Source Voltage	±20	V
E_{AS}	Single Pulsed Avalanche Energy (2)	857	mJ
I_{AR}	Avalanche Current (1)	50	A
E_{AR}	Repetitive Avalanche Energy (1)	12.6	mJ
dv/dt	Peak Diode Recovery dv/dt (3)	5.5	V/ns
P_D	Total Power Dissipation (T_C=25°C)	126	W
	Linear Derating Factor	0.84	W/°C
T_J , T_{STG}	Operating Junction and Storage Temperature Range	- 55 to +175	°C
T_L	Maximum Lead Temp. for Soldering Purposes, 1/8. from case for 5-seconds	300	

Thermal Resistance

Symbol	Characteristic	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case	--	1.19	°C/W
$R_{\theta CS}$	Case-to-Sink	0.5	--	
$R_{\theta JA}$	Junction-to-Ambient	--	62.5	

Electrical Characteristics (T_C=25°C unless otherwise specified)

Symbol	Characteristic	Min.	Typ.	Max.	Units	Test Condition
BV_{DSS}	Drain-Source Breakdown Voltage	60	--	--	V	V_{GS}=0V,I_D=250µA
$\Delta BV/\Delta T_J$	Breakdown Voltage Temp. Coeff.	--	0.063	--	V/°C	I_D=250µA ***See Fig 7***
$V_{GS(th)}$	Gate Threshold Voltage	2.0	--	4.0	V	V_{DS}=5V,I_D=250µA
I_{GSS}	Gate-Source Leakage , Forward	--	--	100	nA	V_{GS}=20V
	Gate-Source Leakage , Reverse	--	--	-100		V_{GS}=-20V
I_{DSS}	Drain-to-Source Leakage Current	--	--	10	µA	V_{DS}=60V
		--	--	100		V_{DS}=48V,T_C=150°C
$R_{DS(on)}$	Static Drain-Source On-State Resistance	--	--	0.024	Ω	V_{GS}=10V,I_D=25A (4)
g_{fs}	Forward Transconductance	--	32.6	--	℧	V_{DS}=30V,I_D=25A (4)
C_{iss}	Input Capacitance	--	1770	2300	pF	V_{GS}=0V,V_{DS}=25V,f =1MHz ***See Fig 5***
C_{oss}	Output Capacitance	--	590	680		
C_{rss}	Reverse Transfer Capacitance	--	220	255		
$t_{d(on)}$	Turn-On Delay Time	--	20	40	ns	V_{DD}=30V,I_D=50A, R_G=9.1Ω ***See Fig 13*** (4) (5)
t_r	Rise Time	--	16	40		
$t_{d(off)}$	Turn-Off Delay Time	--	68	140		
t_f	Fall Time	--	70	140		
Q_g	Total Gate Charge	--	64	83	nC	V_{DS}=48V,V_{GS}=10V, I_D=50A ***See Fig 6 & Fig 12*** (4) (5)
Q_{gs}	Gate-Source Charge	--	12.3	--		
Q_{gd}	Gate-Drain (. Miller.) Charge	--	23.6	--		

Source-Drain Diode Ratings and Characteristics

Symbol	Characteristic	Min.	Typ.	Max.	Units	Test Condition
I_S	Continuous Source Current	--	--	50	A	Integral reverse pn-diode in the MOSFET
I_{SM}	Pulsed-Source Current (1)	--	--	200		
V_{SD}	Diode Forward Voltage (4)	--	--	1.8	V	T_J=25°C,I_S=50A,V_{GS}=0V
t_{rr}	Reverse Recovery Time	--	85	--	ns	T_J=25°C,I_F=50A
Q_{rr}	Reverse Recovery Charge	--	0.24	--	µC	di_F/dt=100A/µs (4)

Notes;

(1) Repetitive Rating: Pulse Width Limited by Maximum Junction Temperature

(2) L=0.4mH, I_{AS}=50A, V_{DD}=25V, R_G=27Ω. Starting T_J=25°C

(3) $I_{SD} \leq$ 50A, di/dt ≤ 350A/µs. $V_{DD} \leq BV_{DSS}$, Starting T_J=25°C

(4) Pulse Test : Pulse Width = 250µs, Duty Cycle ≤ 2%

(5) Essentially Independent of Operating Temperature

MC78XX/LM78XX

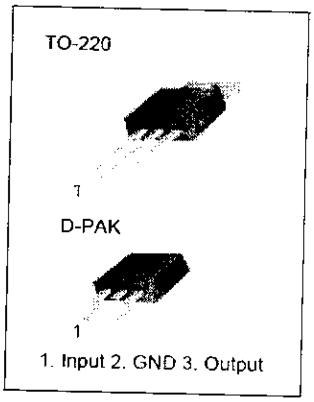
3-terminal 1A positive voltage regulator

Features

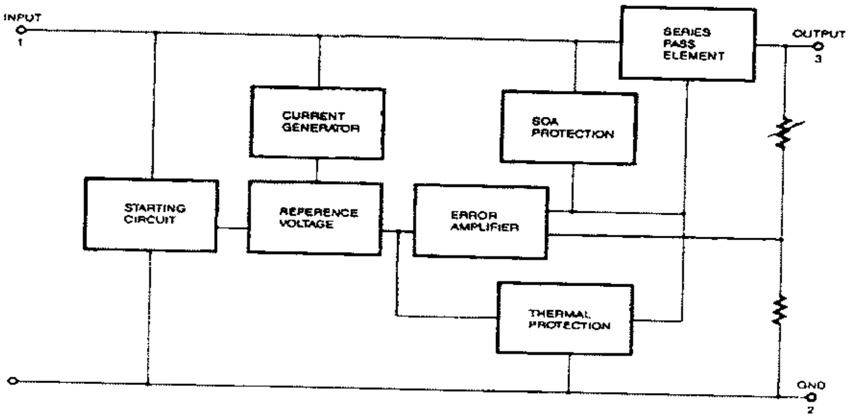
- Output Current up to 1A
- Output Voltages of 5, 6, 8, 9, 10, 11, 12, 15, 18, 24V
- Thermal Overload Protection
- Short Circuit Protection
- Output Transistor Safe Operating area Protection

Description

The MC78XX/LM78XX series of three-terminal positive regulators are available in the TO-220/D-PAK package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut-down and safe operating area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents.



Internal Block Digram



Absolute Maximum Ratings

Parameter	Symbol	Value	Unit
Input Voltage (for V_O = 5V to 18V) (for V_O = 24V)	V_I V_I	35 40	V V
Thermal Resistance Junction-Cases	$R_{\theta JC}$	5	°C/W
Thermal Resistance Junction-Air	$R_{\theta JA}$	65	°C/W
Operating Temperature Range (MC78XXCT/LM78XXCT/MC78XXCDT)	T_{OPR}	0 ~ +125	°C
Storage Temperature Range	T_{STG}	-65 ~ +150	°C

Electrical Characteristics (MC7805/LM7805)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I = 10V, C_I= 0.33µF, C_O= 0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		MC7805/LM7805			Unit
				Min.	Typ.	Max.	
Output Voltage	V_O	T_J =+25 °C		4.8	5.0	5.2	V
		5.0mA ≤ Io ≤ 1.0A, P_O ≤ 15W V_I = 7V to 20V V_I = 8V to 20V		4.75	5.0	5.25	
Line Regulation	ΔV_O	T_J=+25 °C	V_O = 7V to 25V	-	4.0	100	mV
			V_I = 8V to 12V	-	1.6	50	
Load Regulation	ΔV_O	T_J=+25 °C	I_O = 5.0mA to1.5A	-	9	100	mV
			I_O =250mA to 750mA	-	4	50	
Quiescent Current	I_Q	T_J =+25 °C		-	5.0	8	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	0.03	0.5	mA
		V_I= 7V to 25V		-	0.3	1.3	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O= 5mA		-	-0.8	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A=+25 °C		-	42	-	µV
Ripple Rejection	RR	f = 120Hz V_O = 8V to 18V		62	73	-	dB
Dropout Voltage	V_O	I_O = 1A, T_J =+25 °C		-	2	-	V
Output Resistance	R_O	f = 1KHz		-	15	-	mΩ
Short Circuit Current	I_{SC}	V_I = 35V, T_A =+25 °C		-	230	-	mA
Peak Current	I_{PK}	T_J =+25 °C		-	2.2	-	A

- Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Electrical Characteristics (MC7806)

(Refer to test circuit .0°C < T_J < +125°C. I_O = 500mA. V_I = 11V. C_I= 0.33μF. C_O= 0.1μF. unless otherwise specified)

Parameter	Symbol	Conditions		MC7806			Unit
				Min.	Typ.	Max.	
Output Voltage	V_O	T_J =+25 °C		5.75	6.0	6.25	V
		5.0mA ≤ I_O ≤ 1.0A, P_D ≤ 15W V_I = 8.0V to 21V V_I = 9.0V to 21V		5.7	6.0	6.3	
Line Regulation	ΔV_O	T_J =+25 °C	V_I = 8V to 25V	-	5	120	mV
			V_I = 9V to 13V	-	1.5	60	
Load Regulation	ΔV_O	T_J =+25 °C	I_O =5mA to 1.5A	-	9	120	mV
			I_O =250mA to750A	-	3	60	
Quiescent Current	I_Q	T_J =+25 °C		-	5.0	8	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1A		-	-	0.5	mA
		V_I = 8V to 25V		-	-	1.3	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O = 5mA		-	-0.8	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A =+25 °C		-	45	-	μV
Ripple Rejection	RR	f = 120Hz V_I = 9V to 19V		59	75	-	dB
Dropout Voltage	V_O	I_O = 1A, T_J =+25 °C		-	2	-	V
Output Resistance	R_O	f = 1KHz		-	19	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A=+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J =+25 °C		-	2.2	-	A

- Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

1N4001 - 1N4007

Features

- Low forward voltage drop.
- High surge current capability.

DO-41
COLOR BAND DENOTES CATHODE

General Purpose Rectifiers (Glass Passivated)

Absolute Maximum Ratings*

T_A = 25°C unless otherwise noted

Symbol	Parameter	Value							Units
		4001	4002	4003	4004	4005	4006	4007	
V_{RRM}	Peak Repetitive Reverse Voltage	50	100	200	400	600	800	1000	V
$I_{F(AV)}$	Average Rectified Forward Current, .375 " lead length @ T_A = 75°C	1.0							A
I_{FSM}	Non-repetitive Peak Forward Surge Current 8.3 ms Single Half-Sine-Wave	30							A
T_{stg}	Storage Temperature Range	-55 to +175							°C
T_J	Operating Junction Temperature	-55 to +175							°C

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

Thermal Characteristics

Symbol	Parameter	Value	Units
P_D	Power Dissipation	3.0	W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	50	°C/W

Electrical Characteristics

T_A = 25°C unless otherwise noted

Symbol	Parameter	Device							Units
		4001	4002	4003	4004	4005	4006	4007	
V_F	Forward Voltage @ 1.0 A	1.1							V
I_{rr}	Maximum Full Load Reverse Current, Full Cycle T_A = 75°C	30							µA
I_R	Reverse Current @ rated V_R T_A = 25°C T_A = 100°C	5.0 500							µA µA
C_T	Total Capacitance V_R = 4.0 V, f = 1.0 MHz	15							pF

Typical Characteristics

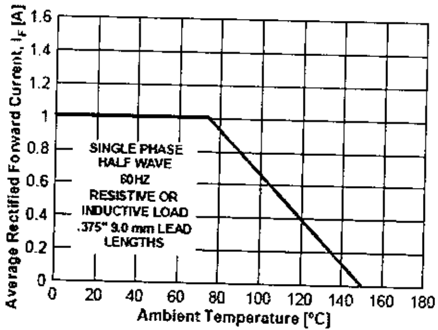


Figure 1. Forward Current Derating Curve

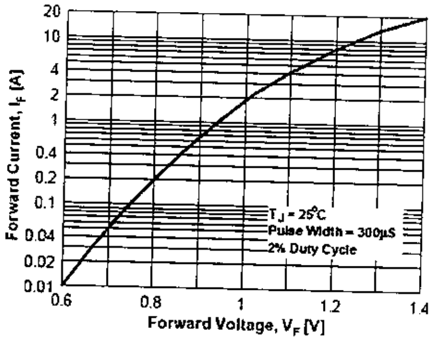


Figure 2. Forward Voltage Characteristics

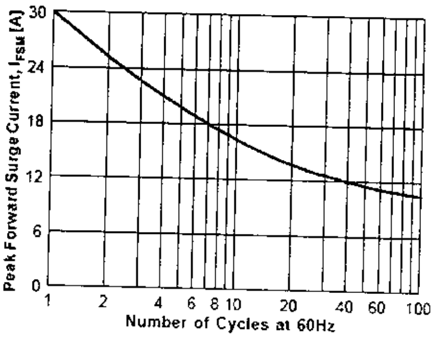


Figure 3. Non-Repetitive Surge Current

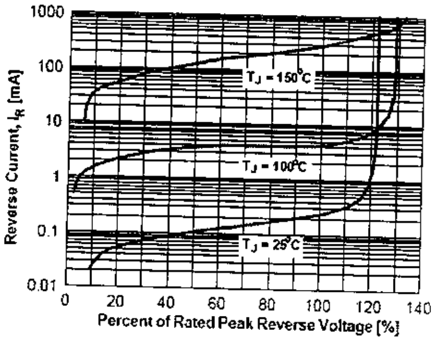


Figure 4. Reverse Current vs Reverse Voltage