IMPLEMENTATION OF AN AUTONOMOUS PHOTOVOLTAIC BASED DC SUPPLY WITH MOTOR GENERATOR BACKUP

A Master's Thesis

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Chairman of the Department

We certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Electrical and Electronics Engineering.

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ABSTRACT

IMPLEMENTATION OF AN AUTONOMOUS PHOTOVOLTAIC BASED DC SUPPLY WITH MOTOR GENERATOR BACKUP

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A photovoltaic (PV) generator based DC power supply with a gasoline motor generator backup is designed and implemented. The system employs PV generators as the primary power source,lead acid batteries as the storage unit and the motor generator set as the back up power source. The system operates under the management of a microprocessor based controller. The controller ensures an uninterrupted power flow to the load by utilizing back up power sources when the solar power is insufficient. A DC/DC converter is implemented as a power conditioning unit between the PV generators and storage batteries. The duty cycle of this converter is adjusted by the controller to keep the PV generator of their maximum power point of operation.

Key words: Maximum power point tracking in PV systems,Motor generator back up for PV systems

Science Code:608.01.05

ÖZ

FOTOVOLTAIK TABANLI VE MOTOR GENERATOR GRUBU
DESTEGINDE OTOMATIK DOGRU AKIM GUC KAYNAGI

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Fotovoltaik generator tabanli ve benzinli motor generator grubu desteginde bir D.A. guc kaynagi tasarlanmis ve imal edilmistir. Sistem fotovoltaik generatorleri ana kaynak, kursun asit bataryalari depolama birimi ve motor generator grubunu da yedek kaynak olarak kullanmaktadir. Sistem bir mikroislemcinin kontrolu altinda calismaktadir. Denetlec gunes enerjisinin yetersiz oldugu zamanlarda yedek kaynaklari kullanima alarak yuklerin kesintisiz enerji almasini saglar. Bir DA/DA çevirgeç fotovoltaik generatorler ile depolama bataryalari arasinda guç duzenleme birimi olarak kullanilmistir. Bu birimin çevrim orani mikroislemci tarafindan fotovoltaik generatorlerin maksimum guc noktasinda çalismasini saglayacak sekilde ayarlanmaktadir.

Anahtar Kelimeler: Fotovoltaik sistemlerde maksimum guc noktasi izleme, Fotovoltaik sistemlerde motor generator grubunun yedek guc kaynagi olarak kullanimi.

Bilim Dali Sayisal Kodu:608.01.05

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CHAPTER I

INTRODUCTION

1.1 Solar Energy as a Renewable Energy Resource

The conventional energy sources such as petroleum or coal have finite behavior and these are the main sources of environmental pollution. In recent years alternative energy sources have been receiving increasing attention. Sun and wind energy are the most promising alternative sources of energy.

The complementary nature of sun in rural areas make these energy sources more valuable in supplying energy to isolated loads. The importance of hybrid power systems containing solar, wind and diesel generators is that, there is an increasing demand for such systems as an autonomous electrical supply for microwave communication systems, radio repeater stations, agricultural systems, hospitals and so forth. The utilization of hybrid power systems in rural areas will eliminate the high cost of power supplies and their maintenance for the radio link repeater systems, rural telephone networks and agricultural establishments. So hybrid power systems can supply remotely isolated electrical energy demanders as well as being able to contribute to the increasing energy demand all over the world.

1.2 Description of the Photovoltaic Based Autonomous Supply with Motor Generator Back-up implemented within the scope of this Thesis

The aim of this study is the practical realization of photovoltaic (PV) energy usage which is one of the alternative energy sources. Unlike other sources of energy PV energy is infinite, non polluting and free. PV energy is obtained by direct conversion of sunlight to electricity. This source of energy is especially suitable for isolated or remote loads. Since these loads are away from the grid it is becoming economical to use PV for this type of loads.

The energy obtained from the PV panels is proportional to the instantaneous solar light intensity. Since this light intensity is continuously changing, the energy output of the panels also changes. Therefore PV panels are usually used in combination with storage batteries. The loads are connected in parallel with the storage batteries. In this way the loads are supplied by a constant voltage source. When the solar power is greater then the power demand of the loads the batteries are charged and when the solar power is unavailable or is not sufficient the loads are supplied by the batteries. Therefore the batteries used in PV systems must be efficient and have low leakage or self discharge rates.

The battery voltage must be kept in certain limits otherwise the batteries are permanently damaged. Therefore the PV panels are never directly connected to the batteries. A power conditioning circuit is required between the PV panels and the storage batteries. For the most simple case this power conditioning circuit must protect the batteries from overcharge and deep discharges. When the battery voltage reaches its upper limit PV panels must be disconnected and when the battery voltage reaches its lower limit either the loads must be disconnected or a second backup power source must be utilized.

The block diagram of the system implemented within the scope of this thesis is shown in figure 1.1 In this system a DC/DC converter is used between the PV panels and the storage batteries as the power conditioning unit. A microprocessor based control system controls the duty cycle of this converter. When the voltage versus current characteristics of PV panels are examined, it is seen that PV panels deliver their maximum power at a certain point on this characteristic. [Sec 2.1] By measuring the voltage and current of the PV panels the microprocessor unit adjusts the duty cycle of the chopper to track the maximum power point. Hence the PV panels are used in most efficient way. The microprocessor based controller also measures the battery voltage and when it reaches its maximum value, the so called float charge voltage the duty cycle of the chopper is adjusted to keep the battery voltage constant at this value. In float charge mode, maximum power point is not tracked and any further rise of the battery voltage is not allowed.

In PV based energy systems solar energy may not be sufficient for the energy demand of the loads especially in long cloudy periods. Some critical loads such as communication systems require are discharged a back up power source must be utilized.

The final aim of this research work is the integration of a mini gasoline motor generator set to the PV energy system. The microprocessor based controller also controls the motor generator set. A standard commercially available gasoline motor is modified so that it can be fully controlled from the microprocessor unit. When the solar energy is not sufficient and the batteries are discharged the generator is automatically started and when the batteries are charged it is stopped. The implemented system can be used in remote areas without any human interaction.

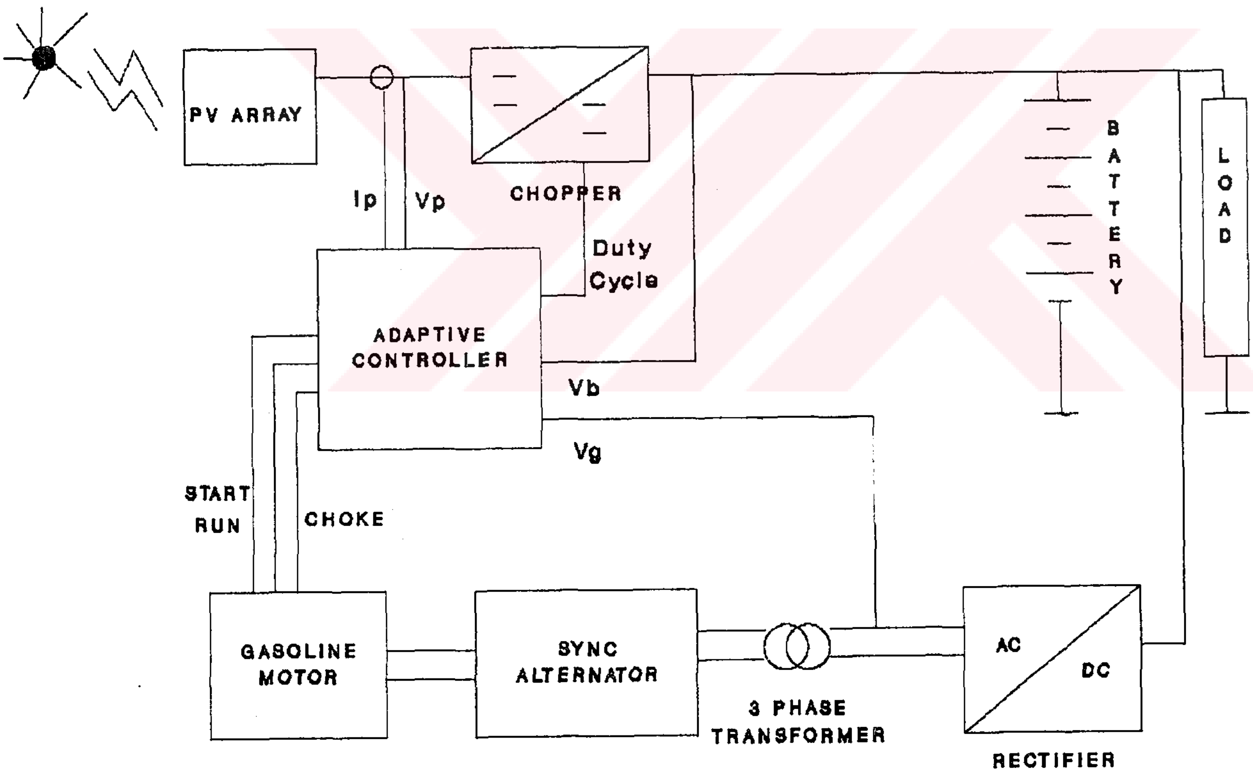

Figure 1.1 Block Diagram of the System

1.3 Previous Work:

This study has begun as the final step of implementation of an fully autonomous supply. Some of the hardware and software an fully autonomous supply. Some of the hardware and software algorithms were previously designed within the scope of the previous research works.

The dc to dc converter that is used as the power conditioning unit of the system has been designed and implemented [1]. This device has the necessary overvoltage and overload control and protection facilities. It was designed as a modular and redundant system. Although the power processing capacity of a single chopper unit is 300 W this capacity can be increased by adding some extra chopper into the circuit. The overall efficiency of the power processing equipment is found to be higher than 90% both theoretically and experimentally.

The microprocessor based controller was designed and implemented within the scope of another research work [2]. The NEC78C10 single chip microcomputer is used as the central processing unit in this design. This chip has the necessary on chip A/D converters,on chip RAM clock generator and timers. Therefore with the use of this single chip microcomputer, the controller card has been implemented with minimum number of external components. This card also contains a pair of external D/A for solar and wind energy conversion systems. The previously implemented microprocessor based controller card was modified to give additional input and output signals before it was used in this study.

Finally for the maximum power point tracking subroutine of the main execution loop of the developed software a previously implemented algorithm is utilized. This algorithm has been developed as a complete program within the scope of another research work [3]. In this study that program has been used as one of the subprograms of the developed software.

1.4 Scope of the Thesis

The major contributions made in the development of the Photovoltaic Based Autonomous Supply with Motor Generator Back-Up are as summarized below.

1) System design and engineering.

2) Modification the microprocessor card according to the needs of the new system.

3) Extending and upgrading the software facilities developed in [3] to meet the requirements of the new system.

4) Modifying the commercially available gasoline engine to have fully automatic start/stop and choke control facilities.

5) Design and implementation of the electric ignition and choke control card.

6) Specifying the nameplate data and providing the manufacturing of the 3-phase ac generator.

7) Designing and providing the manufacturing of the shelter.

8) Mounting wiring and testing the system.

In Figure 1.2 the photograph of the shelter building is given. The shelter building has an overall dimension of 1.20m X 3.60m and consist of two independent rooms. The first room has the dimensions of 1.20m X 2.40m and contains the motor generator set.

Figure 1.2 The Photograph of the Shelter Building

In Figure 1.3 a photograph of the motor generator set is given. Figure 1.4 is a detailed view from the gasoline engine. This figure shows the electrically driven choke unit.

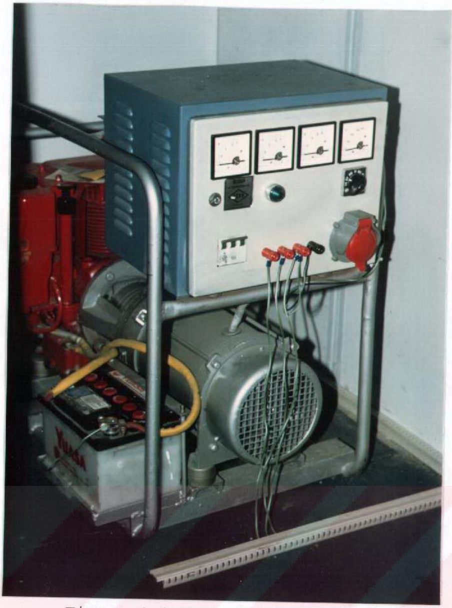

Figure 1.3 Motor Generator Set

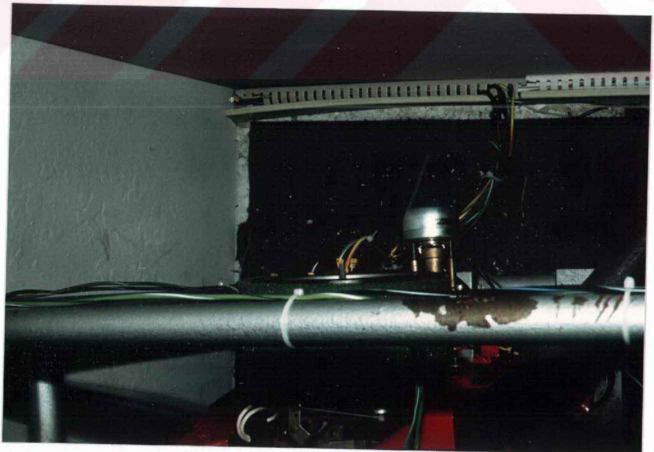

Fig 1.4 The Choke Unit

The second room of the shelter building has dimensions of 1.20m X 1.20m and contains the storage batteries as well as the system controller. Figure 1.5 is a photograph of this room.

Figure 1.5 Controller and Batteries

The implemented hardware and the developed software is explained in chapters 2 and 3. Chapter 2 is devoted to design and implementation of the hardware.

The software developed is described in chapter 3.

The performance of the system is examined by the field tests and the results of these test are presented in chapter 4.

The resulting system can operate as an uninteruptable autonomous dc supply and exhibits a satisfactory performance.

CHAPTER II

SYSTEM DESCRIPTION AND OPERATION

2.1 Photovoltaic Panels

Photovoltaic panels convert the energy radiated by the sun directly into the electrical energy. Since it is impossible to store this energy in the photovoltaic cells; the output voltage of the panel drops to zero when the solar radiation is unavailable. The electric current, hence the power, drawn from the cell is proportional to the intensity of the solar radiation and the area of the panel to receive this radiation.

In Figure 2.1 I-V curve of a typical photovoltaic panel for constant panel temperature and solar irradiation is given. Maximum power that can be extracted from the panel is the multiplication of panel voltage and current at maximum power point and the corresponding power output is represented by the shaded area. In this figure maximum power point (MPP) is marked as point C

In the implemented system the photovoltaic array which consists series parallel combination of several panels are connected to the load and the battery group via a dc to dc converter. This converter maintains operation of the PV array at the maximum power point as the light intensity, panel temperature and load change beyond our control.

I-V characteristics of a typical PV panel varies with solar insolation as shown in Figure 2.2 when the panel temperature is constant.

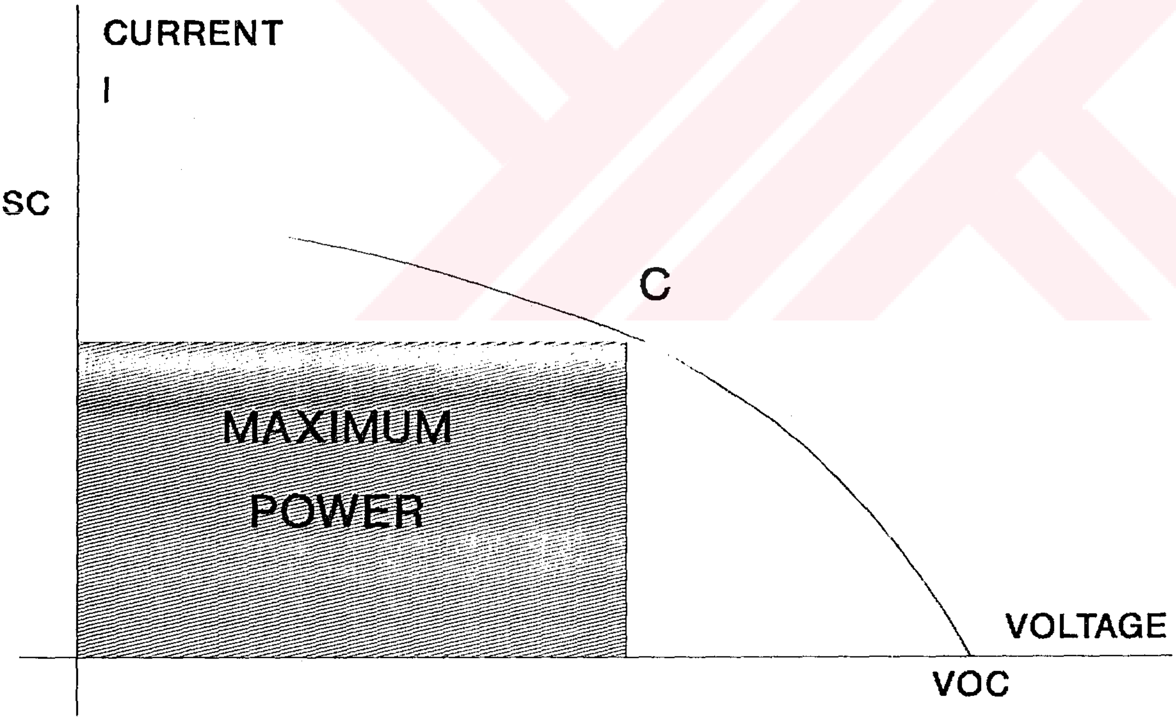

Figure 2.1 I-V Characteristics of the Solar Cell

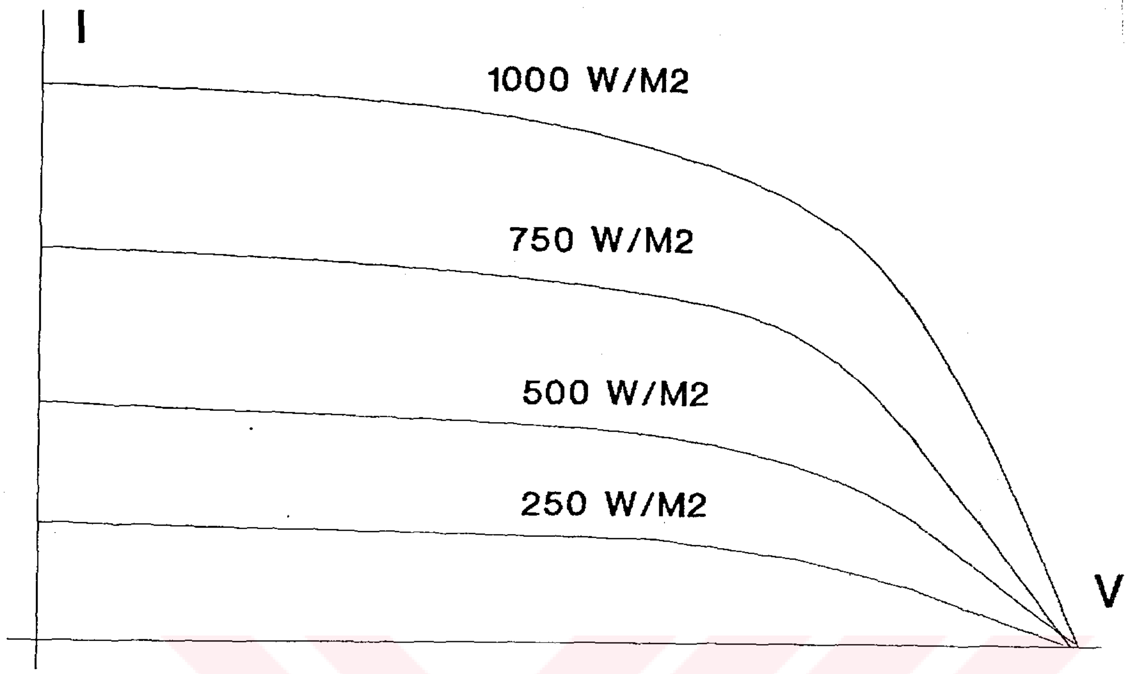

Figure 2.2 I-V Characteristics at Different Light Intensities

It is seen from Figure 2.2 that the output current of a typical PV panel varies with solar insolation proportionally.

On the other hand the I-V characteristics are sensitive to variations in the panel surface temperature as illustrated in Figure 2.3. The maximum power that can be extracted from the panel at constant solar irradiation increases considerably as panel temperature decreases.

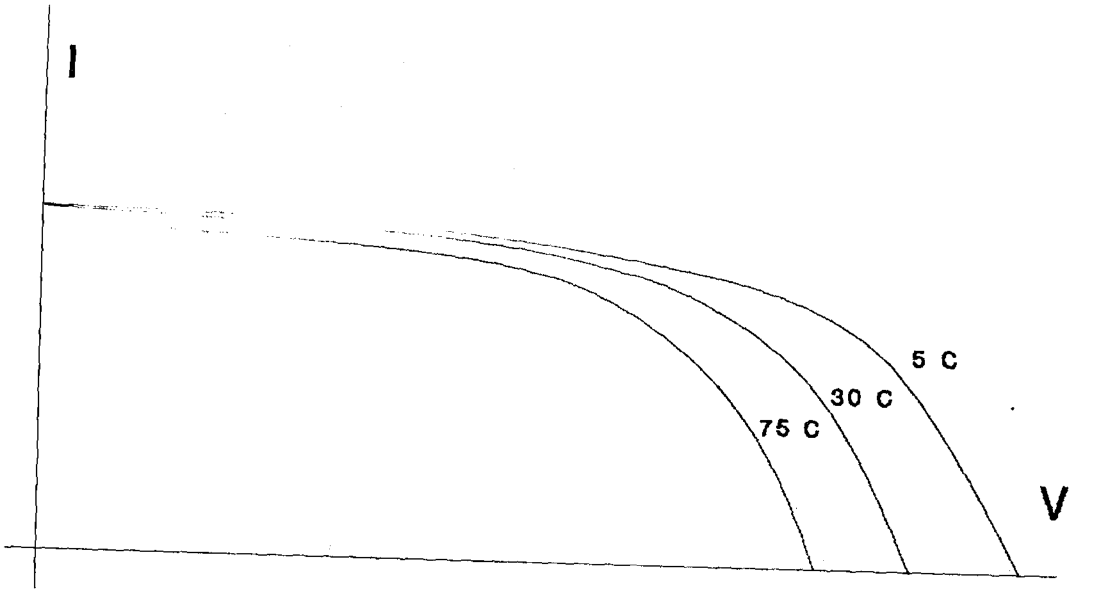

Figure 2.3 I-V Characteristics at Different Temperatures

It can be seen from the figure that the current is less dependent on the temperature while the voltage is reduced when the temperature rises. It can then be concluded that photovoltaic panels work more efficiently at low temperatures.

2.2 The Chopper

The chopper unit is placed between the panel and its load. The DC/DC converter allows operation of the panel at its maximum power point thus resulting in maximum power transfer from solar input to the electrical output. The duty cycle of the chopper is controlled by the microprocessor unit. This unit continuously measures the panel voltage and current; from these two variables calculates the power and adjusts the duty cycle to maintain operation at maximum power point.

The chopper is implemented using a pulse width modulated transistor switch and a low pass filter. [1] The power rating of the chopper is 300 W but in future if required several choppers may be parallel operated for higher power ratings.

2.3 The Batteries

The solar energy obtained from the PV panels must be stored in order to use this energy when the solar energy is not available. For storage of solar energy rechargeable batteries are used. This storage batteries must be as efficient as possible and must have a low leakage current. After the investigation of the available battery types in the market it is seen that Lead-Calcium combination type batteries are the most suitable ones for our applications. The capacity of the batteries are determined according to maximum power which can be extracted from the panel in a day. Therefore 12 V 63 Ah batteries are chosen. In order to obtain 48 V four of this batteries are connected in series.

2.3.1 Characteristics of the Batteries

The batteries used in this system does not require any maintenance at all. They are totally closed so there is no gas output or leakage of the electrolytic. Unlike conventional lead acid batteries the batteries used in this system can be discharged up to zero volts level and then can be recharged again. These batteries can be charged by constant voltage chargers without current limitation. That property is very useful in this particular application since the batteries are sometimes charged by the generator which gives constant voltage. The batteries are charged at a voltage level of 2.3 V per cell. Another important property of these batteries is their very low self discharge rates. These batteries looses only 0.1% of their nominal capacity in a day. As a result of this property if the battery has been kept open circuited for 16 months it has still got the 50% of its capacity.

-Internal Resistance:

Internal resistance of the battery depends on the internal structure as well as the environmental temperature, charging state and near past of the battery. For example if the measurement is done just after charging the battery internal resistance is found higher but if it is done a few hours later internal resistance is found to be lower. The manufacturers data sheets show that for a fully charged battery internal resistance is 40 miliohms and this resistance increases when the battery discharges. For a 50% charged battery internal resistance increases up to 120 miliohm.

-Discharging the Batteries:

The batteries can be fully discharged in 20 hours under a load current of 3.15 A and the maximum current that can be drawn is

440 A. Although these batteries can be deep discharged in order not to shorten their economic life it is not recommended to discharge the batteries under 1.8 V per cell

-Charging the Batteries:

The batteries are charged at 2.3 V per cell constant voltage at 20?C. If the environmental temperature is different than 20?C than a correction factor of -3mV/?C per cell will be used. For these batteries there is no need to limit the charging current. The ripple content of the charging voltage must not exceed 30 mV per cell.

2.4 Gasoline Engine

2.4.1. General Description of the Motor

A gasoline engine was chosen rather then a diesel engine to drive the synchronous generator at constant speed. This is because a gasoline engine does not fail in operation even at very low environmental temperatures such as -30 C. Since the overall system would be a fully automatic one; the gasoline engine should be equipped with an electric starter motor which allows the start/stop operation to be achieved by the microprocessor based controller. A 10 HP gasoline engine has been chosen for this purpose because it was the smallest unit available in the market and having the above requirements. Shaft speed of the motor is internally controlled against variations in the load by a speed governor mechanism. In its original form the motor can only be started manually by the starting key and the choke could only be activated by hand.

2.4.2. Starting Method of the Motor

Standard gasoline engines such as the one used in this thesis have an ignition or starting switch and a choke throttle valve control knob on their control panel and these are manually controlled. The motor was modified in such a way that the resulting configuration would be fully controlled by the microprocessor unit without any human interaction.

The starting switch has 3 positions: Off, Run and Start.

Off position stops the running machine.

Run position turns on the ignition system which is normally on when the motor is running but does not turn on the starting motor.

Start position turns on the starter motor which gives the initial movement to the crank shaft of the gasoline engine. As soon as the motor is started, the starter motor must be turned off otherwise it would be damaged. When the switch is released , automatically returns back to its run position thus turning off the power to the starter motor.

The ignition switch described above has four terminals. These terminals are numbered as #1..#4 and the interconnection between the terminals according to switch positions are determined as described in 2.8.4

2.4.3. The Choke Unit

Choke is a throttle valve at the air entry of the carburetor. When the motor is going to be started this valve should be closed which causes the gas air mixture to be enriched, since the motor is initially cold. When the motor heats up this valve is opened otherwise motor runs inefficiently because of too rich mixture.

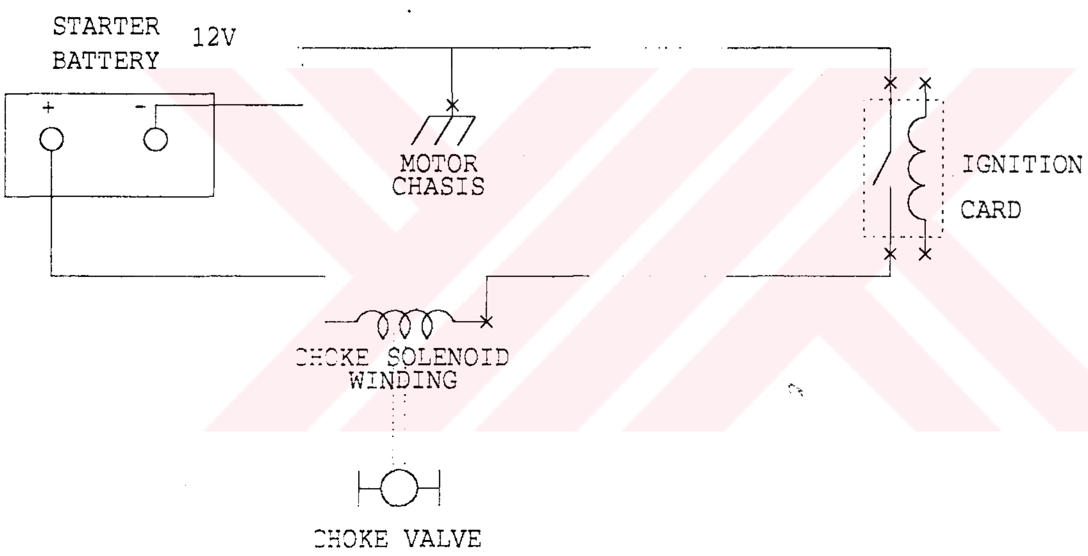

Figure 2.4 Drive Circuit of the Choke Unit

The manual choke knob is modified such that it can be controlled from outside by the microprocessor based controller unit. An electromagnetic solenoid is mounted on the body of the motor. This solenoid when energized closes the choke valve (makes it active) and when de-energized releases the choke valve (makes it passive). The choke solenoid is supplied by 12 V d.c. and this voltage is taken from the internal battery of the starter motor. This battery do not have any electrical interaction with the solar storage batteries and is used for gasoline motor starting only. In this way ,like starter motor, choke unit can also be controlled from the outside by means of a relay tripped by the microprocessor based controller unit. The following electromechanical system is designed and implemented for controlling the choke unit.

2.8 Microprocessor Based Controller

2.8.1 General Description of 78C10 CPU

The control of the system is based upon NEC 78C10 single chip 8-bit microcomputer. This chip has a built in A/D converter. This facility enables use of minimum number of components on the controller card. The 78C10 has also on chip RAM for limited amount of storage capability. For future improvements of the system there is also an expansion RAM socket on the card.

The microprocessor has four analog inputs from the system under control. These are panel voltage,panel current,battery voltage and the generator voltage. The panel current is passed through a DC current transformer. Other voltages are applied to the microprocessor on chip A/D via voltage dividers.

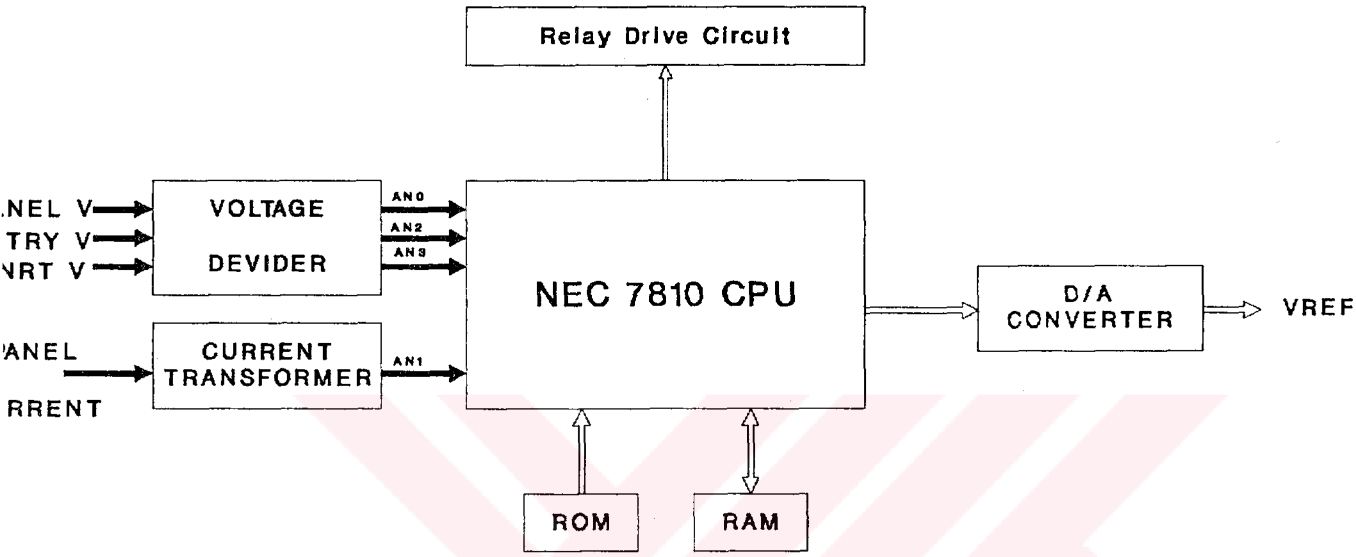

Figure 2.5 Block Diagram of the Microprocesser Card

2.8.2 Description of the Analog-to-Digital Converter

The 78C10 features an 8-bit high speed, high accuracy A/D converter that has 8 multiplexed inputs. The conversion time is 50 ?sec which is fast enough for our application. There are four conversion result registers (CR0,CR1,CR2,CR3). The 8 channel analog input may be operated in either of the two modes: select and scan. In select mode the conversion value of one analog input is sequentially stored in CR0-CR3. In scan mode the upper four channels or the lower four channels may be specified. Then these four channels will be consecutively selected and the conversion results will be stored sequentially in the four conversion result registers. In our application since we have four analog inputs to the microprocessor we have to use the scan mode. In this mode the conversion values of AN0-AN3 or AN4-AN7 are stored into conversion result registers CR0-CR3 in the same order. The selection of higher or lower A/D converter channels is done by masking the A/D channel mode register (ANM) with a special pattern via software. When bit 3 of ANM is 0 the lower four input channels are specified when bit 3 of ANM is 1 the upper four input channels are specified.

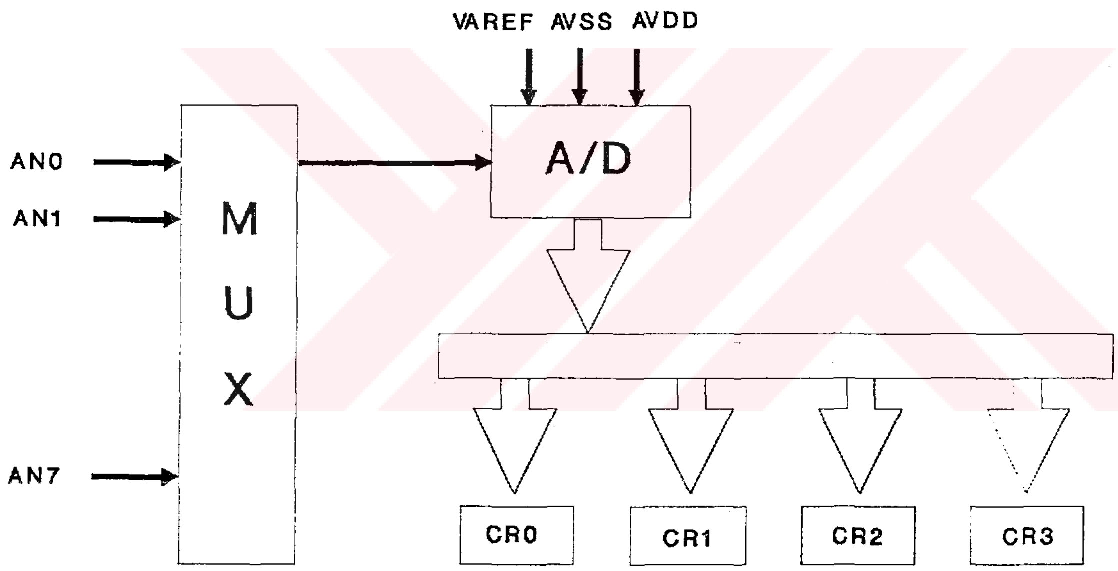

Figure 2.6 Block Diagram of the On-Chip A/D Converter

In the above diagram AV_{DD} is the power supply voltage for the A/D converter. In our design this pin is short circuited with V_{cc} which has +5 V supply voltage. AV_{SS} is the A/D converter power supply ground potential. It sets the conversion's lower limit. This pin is at the same potential with the system ground. V_{Aref} is the reference voltage for the A/D converter. It sets the conversion's upper limit. Any fluctuation in this voltage changes the A/D conversion results considerably. Therefore it must be extremely stable and independent of supply voltage fluctuations. V_{Aref} is chosen to be 2.500V. This reference voltage is supplied with the aid of the LM336 zener reference voltage diode and a variable resistor.

2.8.3 Memory Interface

The NEC 78C10 has a 64K X 8 bit memory addressing capacity. F and D ports of the chip are reserved for external memory interfacing. Both of these ports are 8 bit three-state I/O ports. The 78C10 multiplexes its 16 bit address bus and 8 bit data bus. Therefore an address latch 74HC573 is used for demultiplexing address and data buses.

System ROM occupies the area between the addresses 0000H and 7FFFH. There is an external RAM expansion socket on the card. The external RAM if required will occupy the area between 8000H and 9FFFH. Finally the system has an on chip RAM between the addresses FF00H and FFFFH.

The system control software is stored in ROM. On chip RAM is used for stack and storage of system variables such as choke position,panel power, battery voltage etc..

2.8.4 Input Interface

The microprocessor based controller has four analog inputs. These are panel voltage, panel current, battery voltage and generator voltage. These signal are converted to voltage levels between V_{Aref} and AV_{SS} and applied to the analog inputs of the CPU.

-Panel Voltage:

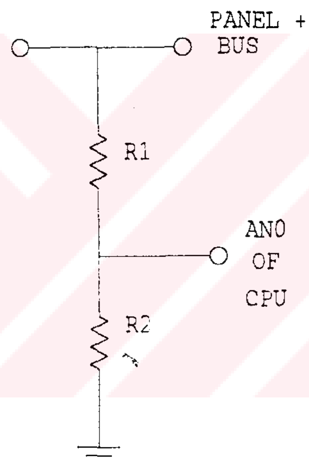

Figure 2.7 Voltage Divider Circuit for Measuring Panel Voltage

This voltage is measured by the use of the resistive voltage divider shown in Figure 2.7 and then applied to AN0 of the 78C10 CPU.

-Panel Current:

For current sensing there are two alternative methods. One of them is to connect a very small series resistance to the output of the panel and measure the voltage drop on this resistor. Second way is the use of a DC current transformer which gives a low current output proportional to the current passing through its core. The first method has the disadvantage of dissipation of considerable amount of power on the current sensing resistor. Therefore the second method is chosen in the implementation.

A current proportional to the actual panel current is passed through R and the voltage drop

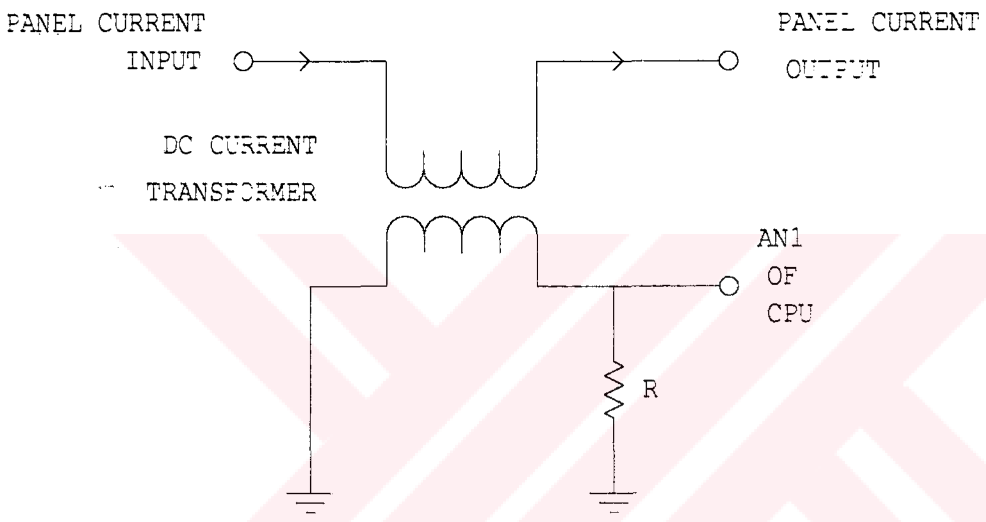

Figure 2.8 DC Current Transformer for Measuring Panel Current

on this resistor is directly applied to the AN1 analog input of the CPU. The transformation ratio of the transformer and R value is chosen such that when maximum panel current is passing, the voltage drop on R must not exceed V_{Aref} value which is the maximum allowable voltage input to the A/D converter.

-Battery Voltage:

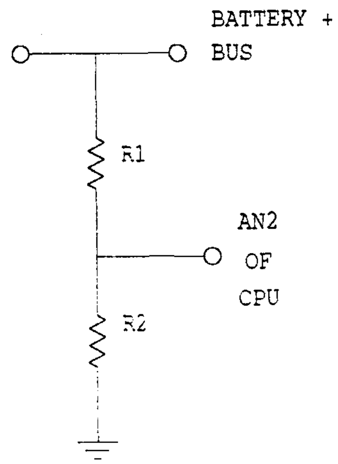

Figure 2.9 Voltage Divider Circuit for Measuring Battery Voltage

Battery voltage is sensed in a way very similar to that of the panel voltage. A potential divider consisting of two metal film resistors are used to step down the battery voltage between V_{Aref} and AV_{SS} values over the normal working range (44<.<55 V)

-Generator Voltage:

Starter motor of the generator must be stopped when the gasoline motor is successfully started. When the gasoline motor is started alternator voltage rises and exceeds a predetermined value. Therefore in order to control the gasoline motor during the start up period, generator voltage must be measured. As it can be seen from the block diagram of the system the generator has 3 phase 380V line-line voltage output. This output voltage is stepped down by a transformer and applied to a 3 phase bridge rectifier. The generator voltage is measured at the input of the rectifier.

Since the generator voltage is in the AC form and it must be isolated from the system ground 1:1 insulation transformer is used.(Figure 2.10). The output of this transformer is rectified and filtered. A DC voltage proportional to the line to line voltage of the generator and with respect to the system ground is therefore obtained. This voltage is scaled down by resistive voltage divider and applied to the AN3 input of the A/D converter of 78C10 CPU.

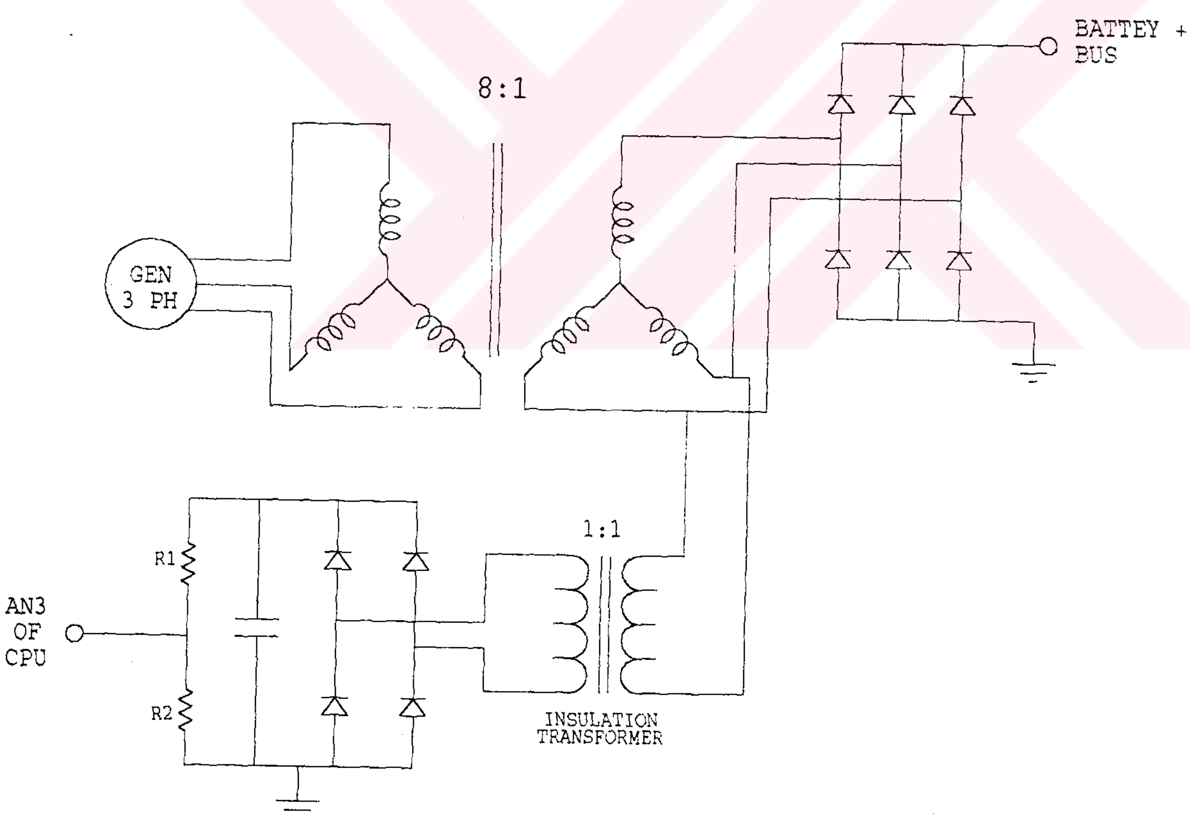

Figure 2.10 The Circuit for Measuring Generator Voltage

2.8.5 Output Interface

The microprocessor based controller card has both digital and analog interfaces. While the digital outputs are taken directly from the ports of the CPU ; the analog outputs are obtained by the aid of external D/A converters.

-Analog Interface:

The analog output of the controller is used to control the duty cycle of the chopper. After the calculation of the duty cycle that keeps the panel at maximum power point is made the microprocessor sends the calculation results in the form of digital data. The data sent by the microprocessor is held by the 74HC373 latch until new decisions are made. The latched data are converted to analog value by DAC801 D/A converter chip. Then this voltage is applied to the chopper drive circuit which adjusts the duty cycle of the chopper.

-Chopper Drive Circuit:

The design and implementation of the chopper drive circuit was achieved within the scope of another research work . The main part of the drive circuit is a pulse width modulator (PWM) voltage controlled IC regulator (SG3524) which consists of two variable width rectangular pulses. These pulses occur symmetrically within alternate half cycles of the fundamental switching frequency and are capable of being modulated by the DC control voltage. This DC control voltage is proportional to the difference between the voltage to be regulated and the reference voltage V_{ref} supplied by the microprocessor based controller unit.

-Digital Interface:

Port B of the CPU has been used for digital output interface. This port has 8 lines each independently programmable as input or output port. Bit 0 if the B port i.e. PB0 is used for 74HC373 latch enable signal. This signal is internally used in the microprocessor based control card.

PB1 is reserved for a second D/A converter latch which was constructed for a probable use in the future for wind energy conversion.

PB2, PB3 and PB4 signals are used for controlling the gasoline motor. The commercially available gasoline motor had a starting switch and a manually controlled choke unit. The motor is modified such that the job of the ignition switch is carried out by relays and the choke unit is controlled by a electromagnetic solenoid.

-Generator Ignition Card

The gasoline motor has four terminal ignition switch which has three positions; OFF, RUN and START. Operation modes and the respective switch positions are as follows:

OFF : Terminal #4 is shorted with motor chassis

RUN : Terminal #2 and #3 is shorted

START : Terminal #1 and #2 is shorted

An electronic ignition card is designed to perform the manual operation of the starting switch in a fully automatic manner This card also activates the choke unit.

The ignition card has three electromagnetic relays; one of which is a single contact while the others are double contact type. As shown in Figure 2.11 the two double contact relays are connected in such a way that all of three functions mentioned above are being performed by their operation.

In the off state terminal #4 should be connected to the chassis of the system. For this purpose normally closed contacts of the two relays are connected in series. In order to start the gasoline engine short circuit between terminal #4 and the chassis should be removed and terminal #1 and #2 should be short circuited. this is achieved by energizing the start relay coil. This opens the normally closed contact thus removing the short circuit between terminal #4 and chassis and closes the normally open contact by connecting terminal #1 to #2.

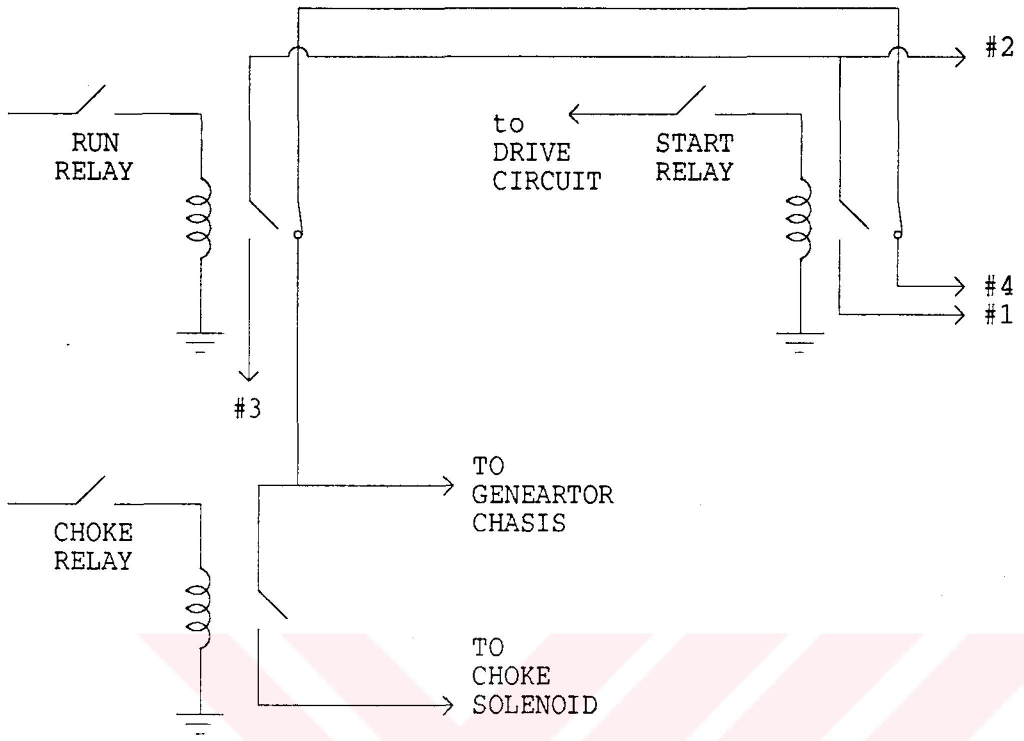

Figure 2.11 Circuit Diagram of Generator Ignition Card

Note that during starting the normally open contact of the relay carries a current of 2.0 A.

Once the motor is started deenergize the start relay and energize the run relay. When the run relay is energized terminals #2 and #3 are being short circuited and terminal #4 is being disconnected from the chassis. This relay carries 11A during the early pulses of the running period and after the motor battery is charged it drops to a lower level of a few amps.

To stop the gasoline engine both relays must be deenergized. This operation automatically connects terminal #4 to chassis.

To activate the choke the choke relay must be energized which demands a very low current of 0.5 amps.

The ignition card has 3 control inputs receiving control signals from the microprocessor card. When the choke signal is low choke solenoid is activated and the motor can be cold started. When start signal is low starter motor is energized. After the gasoline motor is started; starter motor control signal is disabled and run relay is activated. In the run cycle motor charges its own starter battery.

Since digital outputs of 78C10 can deliver only 0.5 mA relay coils cannot be driven directly by the CPU ports. This makes necessary the use of the drive circuits for all relays

-Relay Drive Circuit:

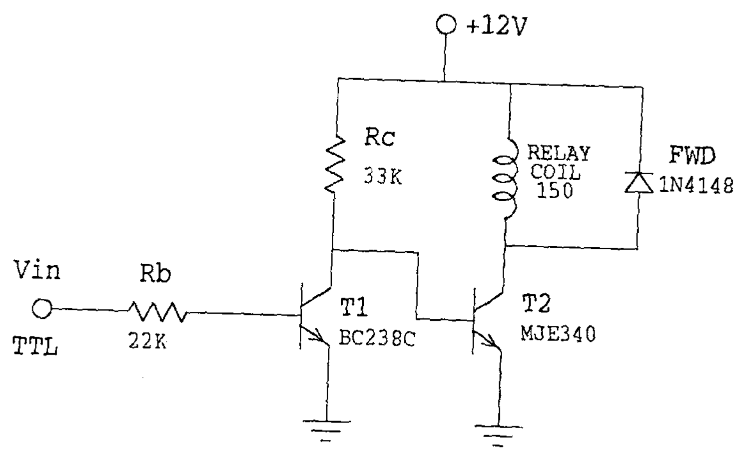

Figure 2.12 Relay Drive Circuit

Each relay drive circuit has the configuration shown in Figure 2.12. In the design the excitation voltage of the relay coils is chosen to be 12 V since this voltage is already available in the system power supply. The relays chosen have a coil current of approximately 60 mA. Since the CPU ports can only deliver a current of 0.5 mA, a double stage relay drive circuit is required as shown in figure 2.12.

The input impedance of the relay drive circuit is chosen such that even at worst conditions it can safely be driven by the CPU ports directly. Since a two stage inverting amplifier is used the input of this drive circuit is active low i.e. when V_{in} is low relay is active.

CHAPTER III

SOFTWARE DEVELOPED

3.1 Objectives of the Software and its Major Functions:

The major functions of the software developed and used in the system are as follows:

* Maximum Power Point Tracking
* Float Charging
* Controlling the operation of the motor generator set.

Solar power is used to charge the batteries whenever it is available. When the solar power is not available , the loads are supplied from the batteries during this period. This operation mode continues until the batteries discharge and the cell voltage drops below a certain limit recommended by its manufacturer. The manufacturer of the batteries used in this system recommends that the batteries must not be discharged further when the cell voltage drops to 1.8 V. One of the objectives of the software is the protection of the batteries from deep discharge.

When 75% of the total capacity of the batteries are discharged, the controller starts the motor generator backup thus recharging the batteries up to their 75% of the full capacity.

At the same time control software protects the batteries from overcharge. The batteries are charged from the panels until maximum cell voltage is reached. The manufacturer of the batteries recommends that the cell voltage must not exceed 2.3 V. After this operation point battery voltage is kept constant. If the panel current is greater than the summation of the load current and the float charge current of the batteries then the duty cycle of the chopper is adjusted to keep the battery voltage at float charge voltage level. This float charge voltage is chosen to be 55 V in this study.

Another objective of the software is to use the panels in the most efficient way. The panels are operated at their maximum power point whenever the demand of the load and the batteries is greater then the maximum available power output.

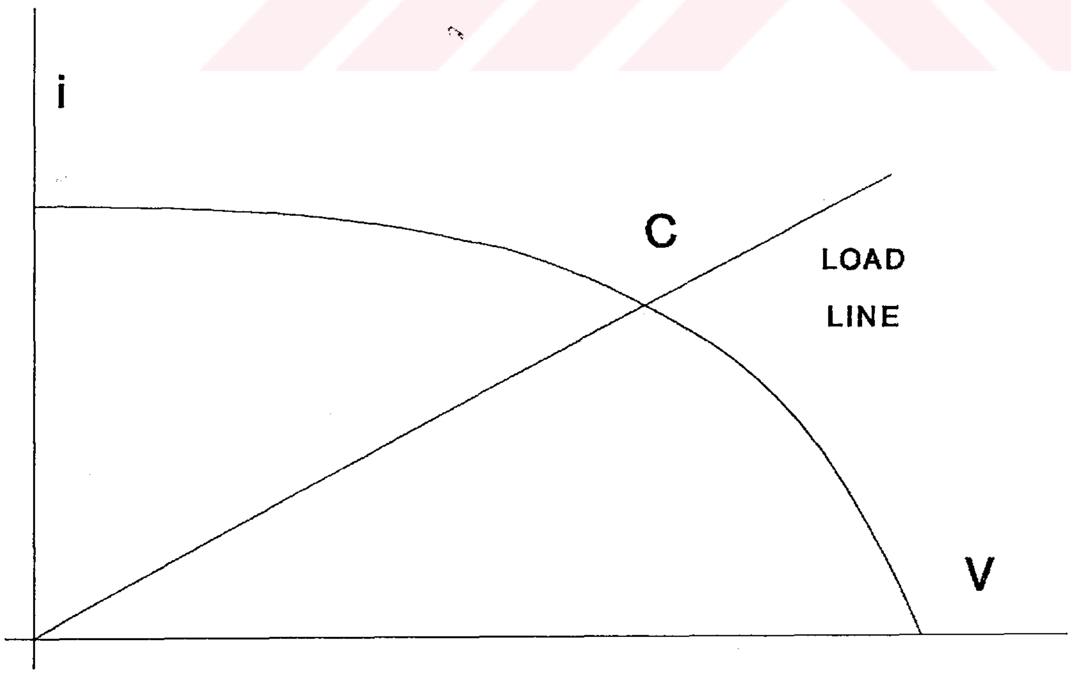

Figure 3.1 Operation of the Chopper with Load

An adaptive control algorithm is used to control the duty cycle of the chopper. This chopper matches the load characteristic to the panel characteristic such that the load line intersects the panel I-V characteristics at maximum power point which is marked as point C in Figure 3.1

3.2 Structure of the Software:

3.2.1. Hardware-Software Interface and Port Map:

Input and output interfaces of the microprocessor are already described in sections 2.8.3 and 2.8.4. Here the operation of the interfaces are investigated from the software point of view. The microprocessor has four analog inputs: Panel voltage, panel current, battery voltage and generator voltage. These signals are connected to the AN0 to AN3 pins of the CPU. Since the microprocessor is used in scan mode, analog conversion results are taken from the conversion result registers. For example in software whenever the CPU needs the current value of the battery voltage it just reads the content of CR2 register.

The analog output is obtained using a D/A chip. The port A of the microprocessor is allocated for this chip. Whenever the CPU needs to send a new reference voltage to the chopper drive circuit, it moves the digital data to port A and enables the latch of the D/A by using PB0.

Digital control signals for the gasoline motor are taken from PB2, PB3 and PB4 bits. They control the run, start and choke signal of the motor. Since the relay drive circuits have active low inputs whenever the microprocessor makes a decision to activate any of these signals it must give a logic zero output to the respective bits of port B.

3.2.2 Program Constants and Variables:

A brief description of the program constants and variables are also included for compactness and better understanding of the program. The source code of the program is given in the appendix. More detailed explanations and definitions are given below.

ROM : This constant holds the beginning address of the read only memory. As it can be seen from the memory map ROM area begins with the address 0000.

RAM : This constant holds the beginning address of the random access memory. In this software on chip RAM of the CPU can meet the storage requirements of this application Therefore an external RAM is not utilized but only the on chip RAM is used.

FULLYOFF : This is the lower limit for V_{ref} value. This constant is set to 90. This value makes the duty cycle of the chopper nearly zero and practically drives the chopper unit to off state.

FULLYON : This is the upper limit for V_{ref} value. This constant is set to 250. This value makes the duty cycle of the chopper nearly one. Therefore the output voltage of the chopper becomes equal to its input voltage. In the maximum power point tracking algorithm V_{ref} value is changed between these two values.

UP and DOWN : These two are the direction of the perturbation flags for up and down perturbation.

VBATMAX : This is the maximum allowable voltage of the battery. According to data sheets of the batteries this voltage is chosen to be 55 V. Since this voltage cannot be applied directly to A/D input, it is reduced by a resistive voltage divider. The digital equivalent of this voltage is found to be 135 and this value is assigned to the VBATMAX program constant. When the battery voltage reaches this value then the batteries are not charged by maximum power point tracking but they are charged by float charge method.

VBATMIN : This is the minimum allowable voltage for the battery. The batteries are discharged until they are 75% discharged and the battery voltage drops to 45 V. Then the generator back up is used for charging the batteries. Similarly this voltage is also stepped down before applying it to A/D and the digital equivalent of this reduced voltage is found to be 114 (72Hex)

VBATGOF : This is the upper limit of the battery voltage for generator charging. For optimum using of the fuel batteries are not fully charged in the generator charge mode. Therefore this voltage is slightly less then VBATMAX. The batteries are 75% charged when their voltage is 53 V and this voltage is chosen for VBATGOF. When this voltage is reached the generator is stopped. Digital equivalent of this voltage is found to be 132.(84Hex)

STCONS : This is a starting constant for the generator. The starter motor of the gasoline motor must be stopped as soon as it is started. The determination of weather the gasoline motor is started or not is done by monitoring the generator voltage. When the gasoline motor is started its shaft speeds exceeds a certain value. This causes the voltage of the generator which is coupled to its shaft to rise above a certain value. When the motor is being started, the generator voltage is continuously measured and compared with this starting constant. As soon as the generator voltage reaches this value, the starter motor is turned off.

TMAX : The starter motor is turned off due to one of the following reasons. The gasoline motor may start successfully - or - fail during the predetermined starting period. The manufacturer of the motor recommends that the starter motor must not be turned on for more then 10 seconds. TMAX is the maximum duration for the starter motor of the generator will be on. This duration is chosen to be 3.5 seconds.

TIME : This is a 8 bit variable for counting the start time. As long as the starter motor is on, this variable is incremented continuously and compared with TMAX constant.

TRY : If the motor can not be started at the end of the TMAX period it is stored for some while and then tried to be started again. This 8 bit variable counts the number of this the gasoline motor is tried to be started.

CHOKE : This flag holds the on/off state of the choke.

OLDPOWER : This 16 bit variable holds the power value of the previous iteration in the maximum power point tracking algorithm.

NEWPOWER : This 16 bit variable holds the power value of the last iteration in the maximum power point tracking algorithm.

VREF : This 8 bit variable holds the last value of the reference voltage for the chopper oscillator. The value of the VREF can change between FULLYOFF and FULLYON program constants and the chopper oscillator adjusts the duty cycle according to this value.

VREFMAX : This 8 bit variable is used in the initialization process. An initial sweep of the duty cycle from FULLYOFF to FULLYON is done and the VREF value where the maximum power is obtained is stored in this variable.

DISTFLAG : This is a flag to indicate the direction of the next step of the perturbation in the maximum power point tracking algorithm.

3.2.3. Main Execution Loop:

The main execution loop is the most important part of the control software. The control software enters this loop after initialization procedure is completed and stays in this loop for ever. The major objective of the main execution loop is maximum power point tracking. An adaptive control algorithm is developed for this purpose. The duty cycle of the chopper is varied in one direction, if a better power value is obtained the controller continues to vary the duty cycle in the same direction until the power output starts to decrease. Otherwise the controller starts to perturb the system in the opposite direction. The flowchart of the main execution loop and the maximum power point tracking algorithm is given in Figure 3.2

The duty cycle and hence V_{ref} value is bounded by FULLYON and FULLYOFF program constants. Therefore before changing V_{ref} these limits must be checked. For example if the direction of the perturbation is up and the V_{ref} value has reached FULLYON then it cannot be incremented any more and direction of the perturbation reverses for avoiding to lock at a constant V_{ref} value.

Another objective of the main execution loop is to keep the battery voltage between VBATMAX and VBATMIN. If the battery voltage reaches its upper limit then the main execution loop calls the float charge mode subroutine. This subroutine tries to keep the battery voltage at VBATMAX and if it drops returns control back to the main

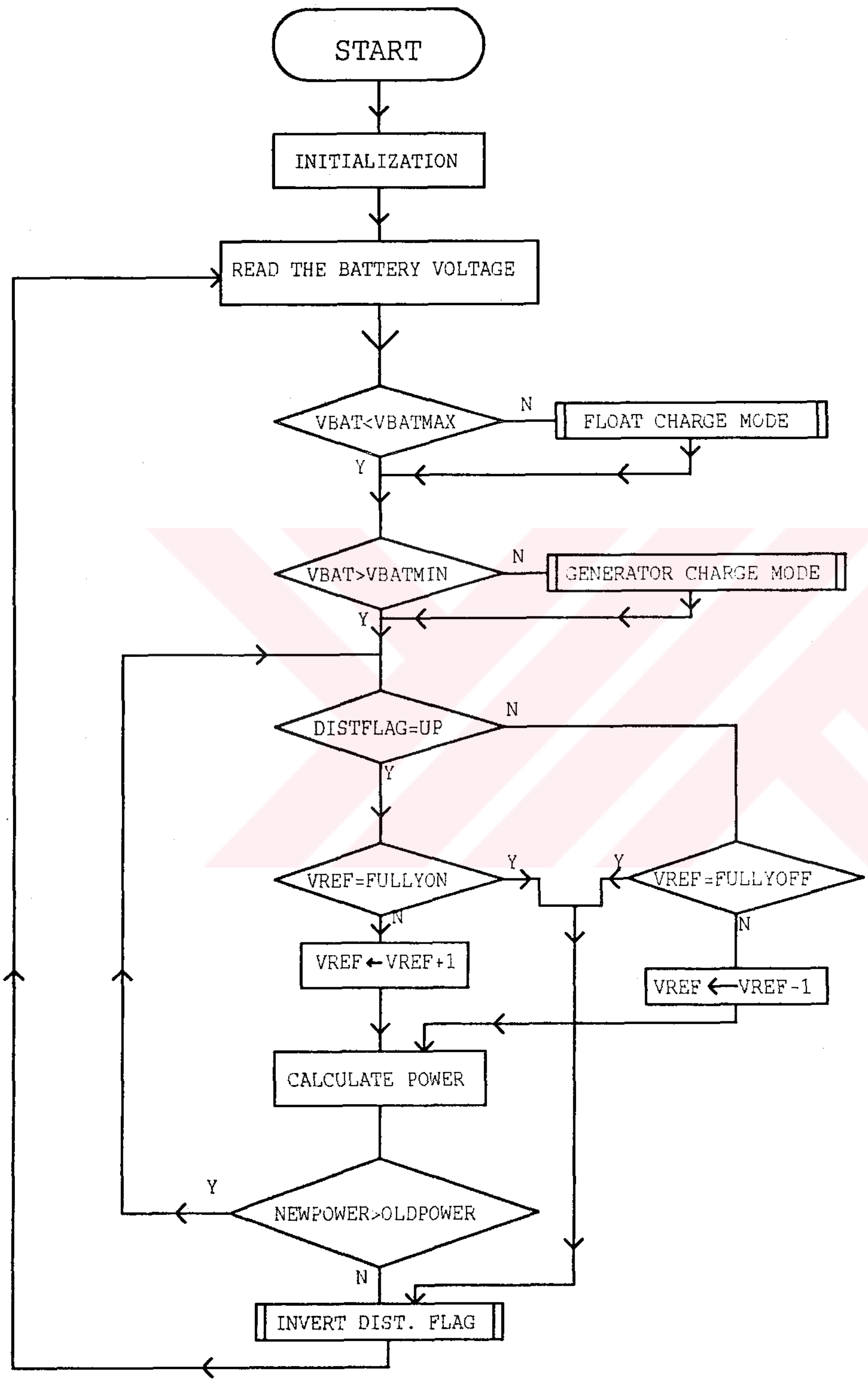

Figure 3.2 Flowchart of the Main Execution Loop

execution loop. On the other hand if the battery voltage drops to its lower limit determined by VBATMIN program constant then the main execution loop calls the generator charge mode subroutine. The generator charge mode subroutine starts the generator and charges the batteries and at the end of charging period it returns control to main execution loop again

3.2.4. Initialization Procedure :

Before entering the main execution loop program variables and registers of the microprocessor must be set to their initial values. Since the reset vector of the microprocessor is at the address 0000H the initialization procedure begins with this address. In this software none of the interrupts of the CPU is used therefore at the very beginning the interrupts are disabled. Then the stack is prepared for later usage of return addresses and register value storage. Stack pointer is set to end of available RAM. The memory mapping register of the 78C10 microprocessor is set for 64 K Bytes of memory configuration. Recall that the ports of the microprocessor are bidirectional ports. Therefore before using them they must be set for input or output by software. In the initialization procedure ports A and B are set to output mode. A/D converters can be used in scan or select mode. Since they will be used in scan mode in the software because of the reasons mentioned in 2.8.1 A/D conversion register is set for scan mode in the initialization procedure. The 78C10 microprocessor has the facility of using working vector register. A working page address is specified in this register and when accessing the memory only the offset of the address is given. In this way programs get shorter and more understandable. Since the internal RAM will be used for all of the storage purposes the working register is set to FFH.

The remaining portion of the initialization procedure is an initial sweep of the duty cycle from fully off to fully on. For every V_{ref} value panel voltage and current is measured then the panel power is calculated. At the end of this initial sweep the V_{ref} value where the panel power is maximum is determined and the main execution loop begins with this initial V_{ref} value.

3.2.5 Float Charge Mode Subroutine

Normally the batteries are charged using maximum power point tracking algorithm. When the panel current becomes greater then the load, the difference current starts to charge the batteries and the battery voltage gradually increases. When this voltage has reached to its upper limit defined by VBATMAX program constant then the main execution loop calls the float charge mode subroutine and the battery voltage is kept constant at this value. The flowchart of this subroutine is given in Figure 3.3.

The duty cycle of the chopper is decreased as long as the battery voltage is above the VBATMAX and it is increased as long as the battery voltage is below the VBATMAX. In this way the battery voltage is kept constant around VBATMAX value. If the battery voltage does not rise to VBATMAX even for the fully on value for the cycle of the chopper then control returns to main execution loop and the maximum power point tracking algorithm becomes active. This return condition happens when the panel current is not sufficient for the demand of the loads and the float charge current of the batteries.

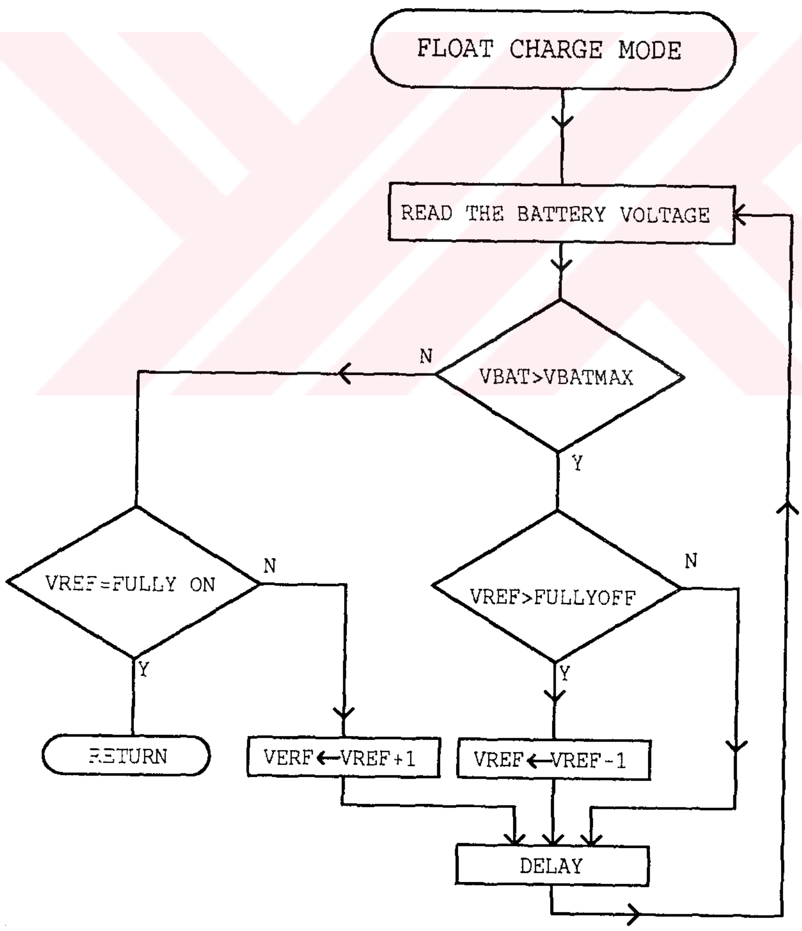

Figure 3.3 Flowchart of the Float Charge Mode Subroutine

3.2.6. Generator Charge Mode Subroutine

When the panel current is less then the load current demand then the difference between the two is supplied from the batteries. This causes the batteries to be discharged and battery voltage to be dropped. When the battery voltage drops below a certain value defined by the VBATMIN constant this subroutine is called by the main execution loop. This subroutine starts the generator driven by a gasoline motor and if necessary it activates the electrically driven choke. The generator remains running until the battery voltage reaches to the value defined by the VBATGOF system constant. When this voltage is reached the generator is stopped and control returns to the main execution loop.

The choke unit of the gasoline motor is necessary to start the motor when it is cold. After the choke is activated motor can be easily started but on the other hand if the choke is activated when the motor is hot then it would be very difficult or impossible to start the gasoline motor since the gas air mixture would be too reach. In the starting algorithm given below at firs the motor is assumed to be hot and it is tried to be started without using the choke unit. The starter motor is kept running for the duration of the TMAX program constant. The developed voltage at the generator is continuously measured within this time period and if the

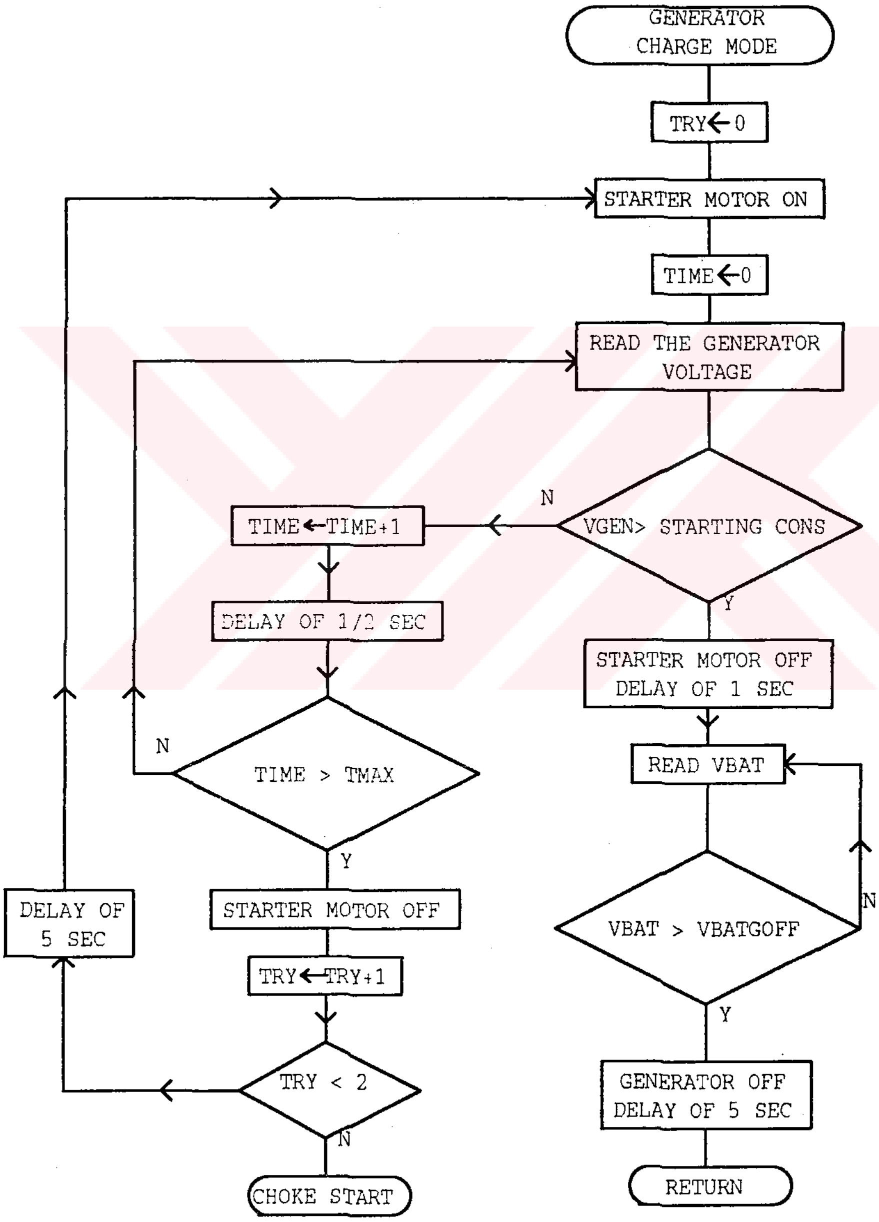

Figure 3.4 Flowchart of the Generator Charge Mode Subroutine

generator voltage exceeds the critical value defined by the starting constant then the starter motor is turned off otherwise the starter motor is energized continuously until the end of TMAX period. If the gasoline motor does not start successfully at the end of TMAX period, the procedure is repeated for the second time. But before the starter motor is again turned on the microprocessor waits for 5 seconds in order that the motor gets ready to be started again. The starter motor is kept running for the duration of TMAX again but at the end of this period if the gasoline motor does not start successfully then the microprocessor assumes that the motor is cold and it cannot be started without using the choke unit.

The second part of the generator charge mode subroutine is the choked starting algorithm. This algorithm is very similar to the first one the only difference is that choke is activated with the starter motor. If the motor successfully starts then the starter motor is immediately turned off but choke is kept active for some time. Another difference with the first algorithm is that the motor is tried to be started for three times not for two times. At the end of third trial if the motor does not start the microprocessor gives error signal and halts.

After the generator is started it begins to charge the batteries. The microprocessor continuously monitors the battery voltage and when the battery voltage reaches the VBATGOF program constant the generator is turned off and the control again returns to the main execution loop and the maximum power point tracking algorithm.

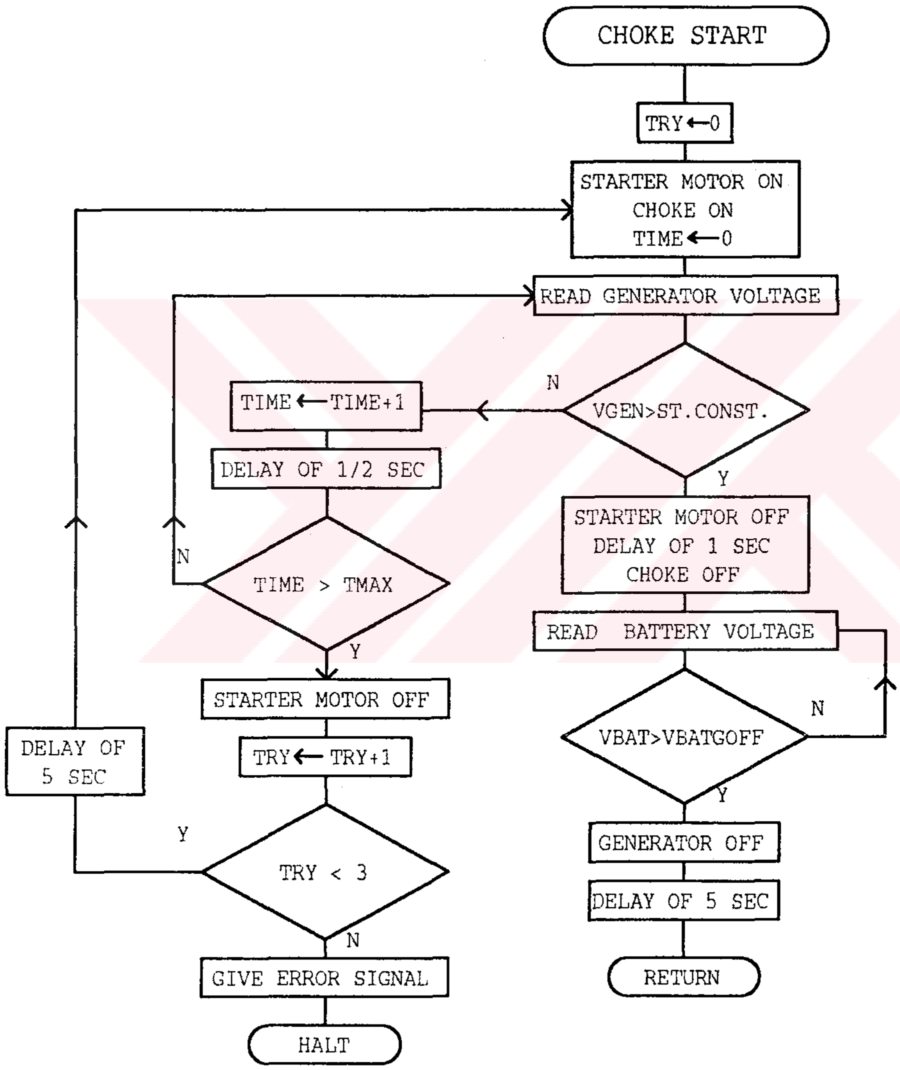

Figure 3.5 Flowchart of the Choked Starting Subroutine

3.2.7 Latch Enable Subroutine :

The data is send from microprocessor to A/D converters using 74LS373 latches. When the microprocessor makes a decision to send a new V_{ref} value to the chopper oscillator, it outputs the digital equivalent of the V_{ref} value to the port A and enables the latch between the port A and the D/A converter. The enable pin of the latch chip requires an active high pulse. This subroutine is used to obtain this pulse whenever a new V_{ref} value is to send to D/A. As it can be seen from the hardware of the microprocessor based controller card the least significant bit of the port B is connected to the D/A latch. Since the enable pulse is active high this bit which is normally low, kept in high for the duration of the enable pulse. The flowchart of this subroutine is given below.

The least significant bit of the port B is ORed by one to make it high and after some delay for pulse duration it is ANDed by zero to make it low.

3.2.8 Complement Disturbance Flag Subroutine :

In the maximum power point tracking algorithm the V_{ref} value is disturbed in either of two directions up or down. When the main execution loops wants to change the direction of the perturbation it calls this subroutine. This subroutine takes the complement of the disturbance flag. If the disturbance flag is up then it is made down and if the disturbance flag is down then it is made up.

CHAPTER IV

EXPERIMENTAL TEST RESULTS

After completing the implementation, the resulting system is tested under actual operating conditions in the field. Since the chopper and the maximum power point tracker are developed within the scope of some previous research works, a detailed investigation of their performance are not repeated here.

The experimental results presented in this chapter therefore covers only:

* the automatic operation of the motor generator set and

* the performance of the overall system managed by the microprocessor based controller.

4.1 Motor-Generator Set

At steady state line to line voltage at the output of the Y/Y connected transformer is measured by a storage oscilloscope. As can be seen from Figure 4.1, this voltage is in the form of a sine wave which has a peak value of 50 V and a frequency of 48 Hz. The synchronous speed and the frequency of the output voltage depends on the shaft speed of the gasoline engine. Although there exists a gas regulator at the carburetor of the motor the shaft speed makes small fluctuations and this effects the output frequency. This frequency fluctuations is in the order of 2 or 3 Hz and has no significant effect for our application since the output power of the generator is converted into DC form.

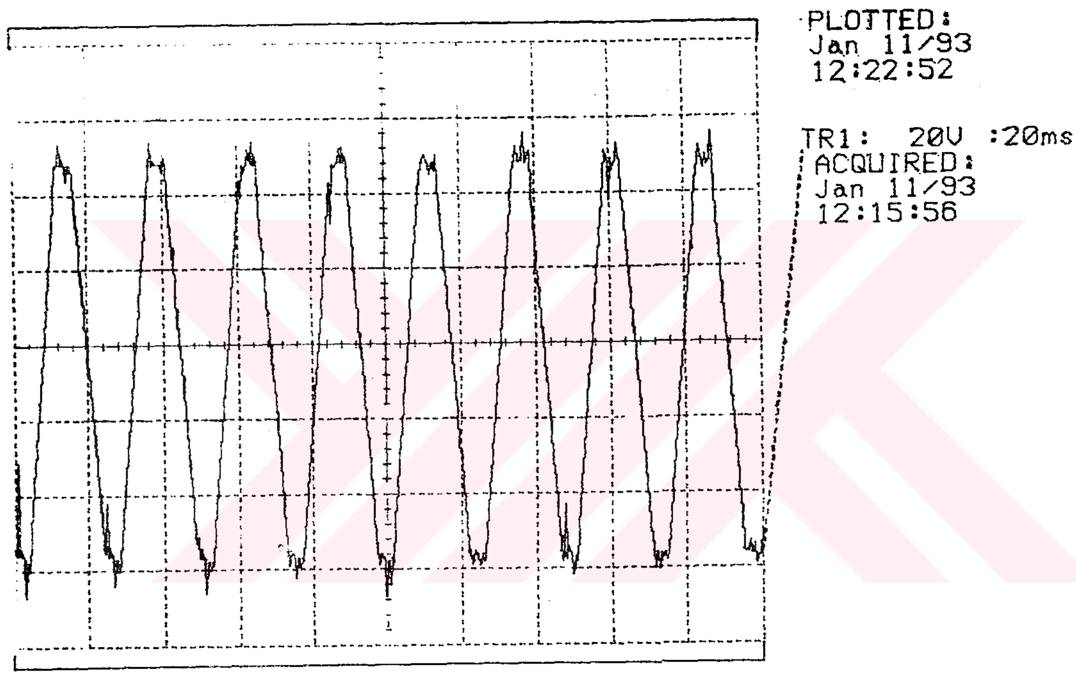

Figure 4.1 Steady State Line Voltage at the Output of the Transformer

The output voltage of the generator is built up as shown in Figure 4.2 during starting period if the microprocessor based controller successfully starts the gasoline engine.

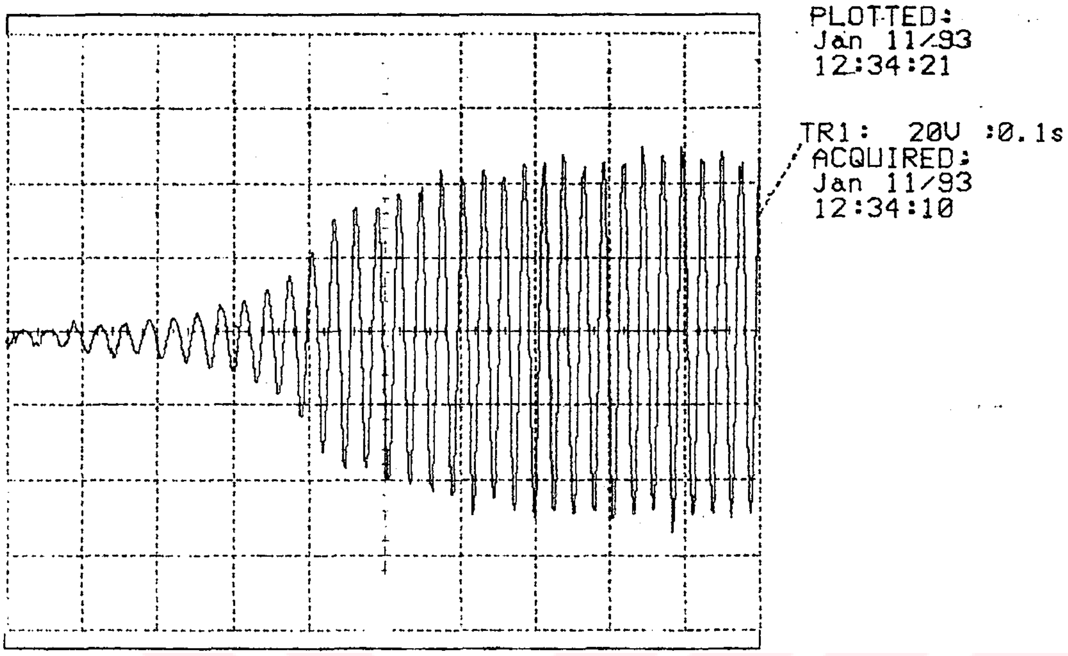

Figure 4.2 Build-up of the Generator Voltage during Starting

It is seen from Figure 4.2 that after the motor is started the generator voltage begins to rise and in 600 or 700 msecs time reaches to its rated value. The microprocessor monitors this variation to make a decision about whether or not the gasoline engine is started and for successful starting to determine the time instant at which the starter motor must be switched off.

As described in section 2.8.4 and figure 2.10 a dc voltage proportional to the peak value of this waveform is obtained. This dc voltage is then applied to the analog input of the CPU. When this voltage exceeds a predetermined value the microprocessor decides that the gasoline motor is successfully started so the starter motor must be turned off. This predetermined value is found experimentally. This value must be chosen very carefully as explained below . If it is chosen to be very low, the generator voltage may reach this value before the gasoline motor successfully started. At this instant if the starter motor is turned off then the gasoline motor would not continue to run and immediately stop. On the other hand if this value is chosen to be very high then the generator voltage will reach this value far after the gasoline motor is started. In this case the starter motor will probably be damaged.

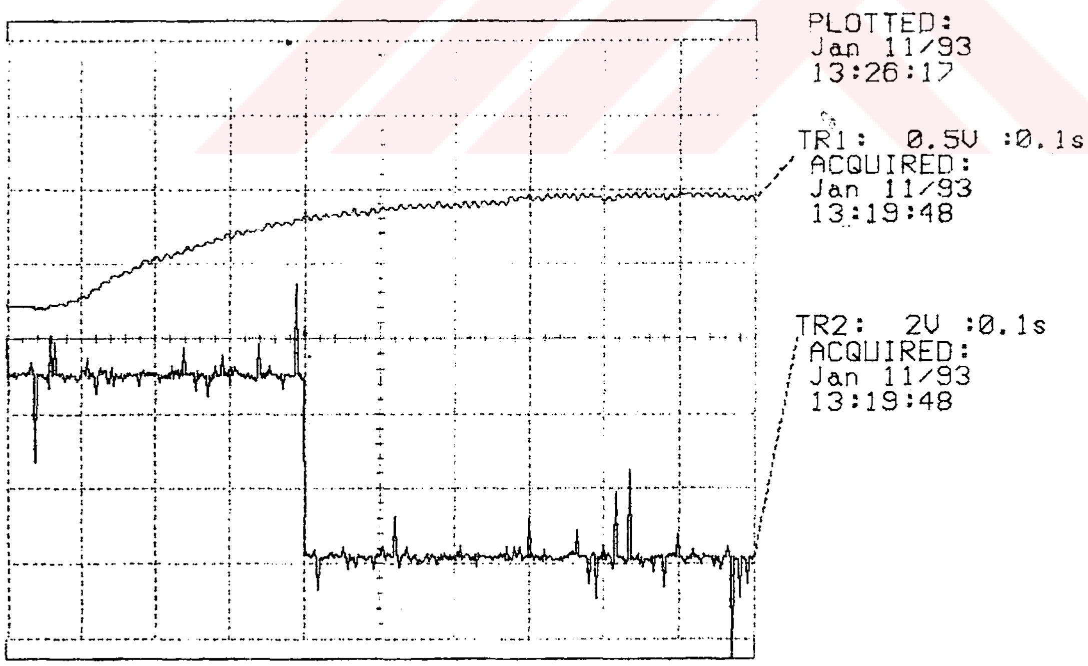

Figure 4.3 Waveforms at AN3 and Start Relay Coil

In the Figure 4.3 upper trace shows the waveform at the AN3 analog entry of the microprocessor. The microprocessor uses this entry for measuring the generator voltage. The lower trace shows a digital waveform which is the microprocessor output for driving the start relay. When this output is at the high level, start relay is activated thus energizing the starter motor and when it is at the low level the starter motor is turned off. As it can be seen on the above figure when the voltage at the AN3 input of the microprocessor exceeds 0.85 V the microprocessor decides that the motor is started and the starter motor is turned off.

As described in section 2.3.6 the gasoline motor is tried to be started 5 times. At the first attempt it is assumed that the gasoline engine is hot and the choke unit is therefore not activated. The starter motor is turned on for 8 seconds. At the end of this time interval if the gasoline motor is not started, the starter motor is turned off. In this case the microprocessor waits for five seconds before the next attempt.

Depending upon the temperature of the motor it is observed to be started at the first or third attempt of starting. The following data is obtained by disconnecting the spark plug of the gasoline motor. Since the motor cannot run in this condition all of the steps for starting are recorded.

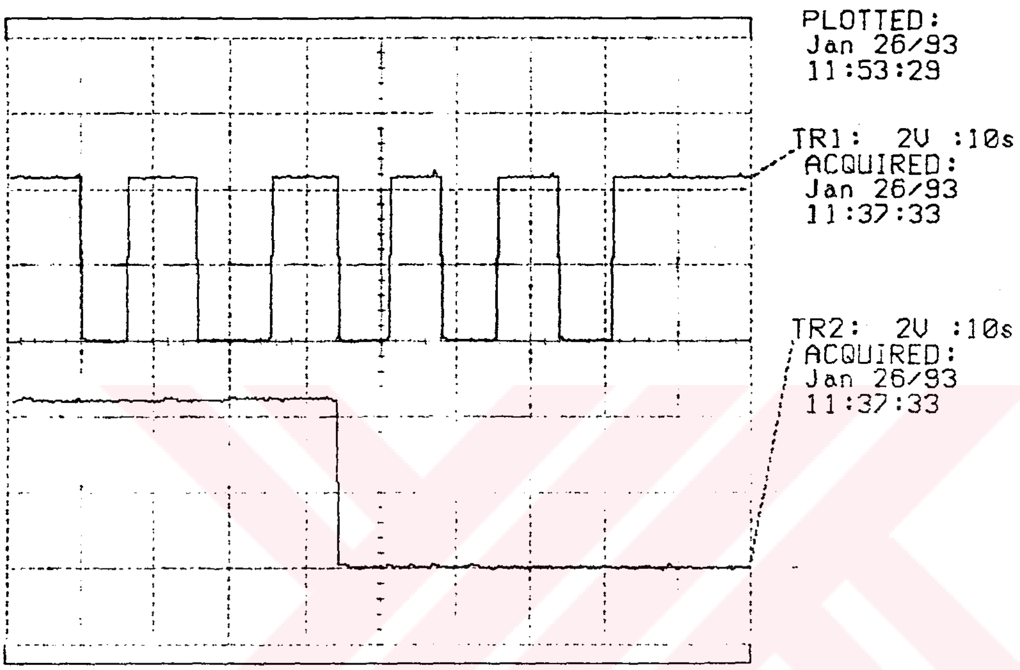

Figure 4.4 Start and Choke Signals at Starting

The upper and lower trace show the start and choke signal respectively. Both of these signal are active low i.e. when trace 1 is high the starter motor is idle and when it is low it is turned on. As it can be seen from the figure at the end of second trial; the choke unit is activated and the motor is tried to be started again for 3 times. this result agrees with the previously developed algorithms and software.

4.2 Performance of the Photovoltaic System

The performance of the photovoltaic system is recorded against the variations of solar insolation. The corresponding test set-up is as shown in Figure 4.5

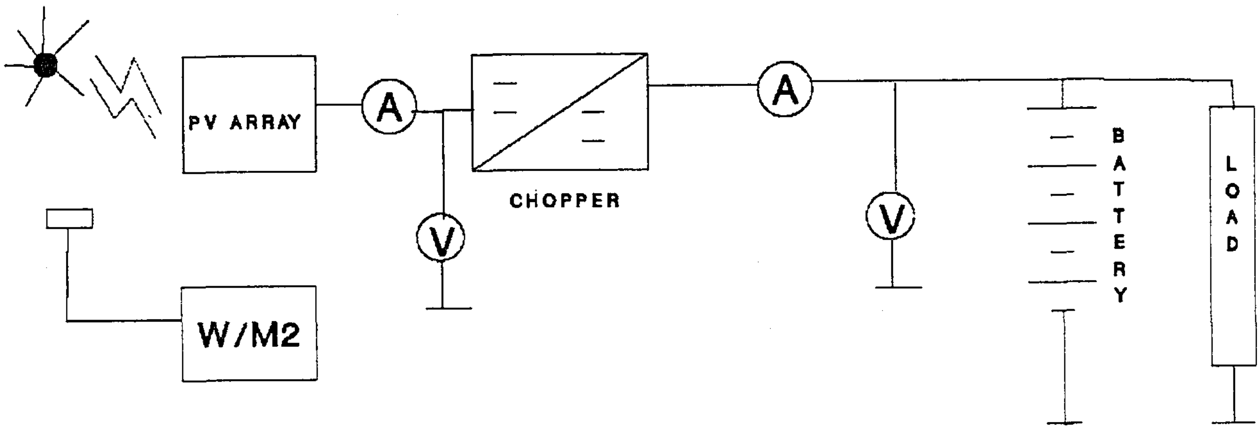

Figure 4.5 Experimental Set-up

Data collected at the output terminals of the photovoltaic array gives information about the electrical power output of the array. On the other hand the data collected at the output of the power processing equipment gives information with respect to the net output power of the overall system. The data collected and the performance values calculated from them are presented in Table 4.1 as a function of solar insolation.

In the table performance values given in 4th, 5th, 6th, 9th and 10th columns are calculated in the following manner.

Experimental $P_{in}=V_{panel} \cdot I_{panel}$

Theoretical P_{in}=4X47X(Solar Insolation)/1000

Note that 4 panels are connected in series to form the PV array each of which has a peak power rating of 47 W_p at 25 C and a solar insolation value of 1000 W/m^2.

$$Error=(P_{in.thor}-P_{in.exp})/P_{in.theor} \times 100 \quad \%$$

$$P_{out}=V_{bat} \cdot I_{out}$$

$$Eff=P_{out}/P_{in.exp} \times 100 \quad \%$$

During this test the microprocessor based controller operates in maximum power point tracking mode. However as can be seen from 4th and 5th columns of the table $P_{in.exp}$ values are always lower than $P_{in.theor}$. But the error is not more than 11%. This is because the panel surface is not as clean as should be, during the test period. This dirt layer obviously filters partially the solar irradiation.

Solar Inso W/M^2	V_{panel} V	I_{panel} A	Experimental P_{in} W	Thoretical P_{in} W	Error %	V_{bat} V	I_{out} A	P_{out}	Eff %
210	54.9	0.65	35.7	39.5	9.6	50.5	0.5	25.3	50
254	55.0	0.80	44.0	47.7	7.7	50.2	0.7	35.1	79
295	55.0	0.90	49.5	55.5	10.8	51.2	0.8	40.8	82
315	55.5	1.00	55.5	59.0	5.9	51.3	0.8	46.2	83
326	55.5	1.00	55.5	61.3	9.4	51.4	1.0	51.4	92
340	55.5	1.10	61.1	63.9	4.3	51.4	1.0	51.4	84
350	55.8	1.10	61.4	65.8	6.6	51.4	1.0	51.4	83
380	56.0	1.20	67.2	71.4	5.8	51.2	1.1	56.3	83
414	56.2	1.30	73.1	77.8	6.0	51.6	1.2	62.0	84
400	56.2	1.30	73.1	77.8	6.0	51.6	1.1	56.8	77
387	56.0	1.20	67.2	72.7	7.5	51.6	1.1	56.8	83

Table 4.1 Results of the Photovoltaic System Test

The efficiency of the power processing and control equipment (chopper + microprocessor based controller + power supply for electronic circuits) are observed to vary between 50% and 92%. This is an expected result because as stated in [1] the chopper efficiency largely dependent upon the operating point. That is at low power outputs the efficiency may be lower than 50%, but rises gradually as the power transferred by the chopper increases and exceeds 90% for operation around the rated operating point.

In conclusion, the experimental results have shown that the microprocessor based controller ensures the operating point of the system at the so called maximum power point.

CHAPTER V

CONCLUSIONS

The aim of this study is the practical realization of photovoltaic energy usage which is one of the alternative energy sources. This energy is obtained from the PV array and stored in the batteries for using that energy whenever it is needed.

The photovoltaic energy has been utilized in most efficient manner by making use of a maximum power point tracker. The maximum power point tracker is implemented using a chopper operating under the control of the microprocessor based controller. The chopper ensures the operation of the photovoltaic panels at the most efficient operating point.

The main objective of this research work is to implement an autonomous supply. In photovoltaic based systems especially in cloudy seasons of year solar energy may not be sufficient to supply the power demand of the loads. Some critical loads such as communication systems require uninterrupted electrical energy flow. Therefore when the batteries are discharged because of insufficient solar energy a back up power source must be utilized.

In this study a mini gasoline motor generator set is modified so that it can be fully controlled by the microprocessor based controller unit and then this motor-generator set is used as the back up power source of the implemented system.

Finally the overall system has been installed in an independent shelter building.

Some modification on the present form of the system may improve the performance and quality of the product. These are listed below.

i) Temperature compensation on the float charge voltage of the batteries.

ii) Stored charge status of the batteries may be predicted by taking into account internal resistance and temperature of the batteries.

iii) A load shedding mechanism is required in order to prevent complete discharge of the batteries in the case of a device failure.

iv) Signaling, alarming and fault diagnostigs.

v) Modification to allow manual operation.

vi) Depending upon the results of the field test data collected in the long term the set values of the system may be re-adjusted.

Wind energy conversion system can be added as the secondary source of energy resulting in a hybrid system. The microprocessor based controller has the necessary free input and output interfaces for this system and the both systems can be simultaneously controlled.

REFERENCES

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A P P E N D I X

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            APPENDIX A  ASSEMBLER LISTING OF THE SOFTWARE

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     AN ADAPTIVE CONTROLLER PROGRAM FOR THE AUTONOMUS DC POWER SUPPLY

                    WITH MOTOR GENERATOR BACKUP

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                    DATE: SEPTEMBER 1992


*****************************************************************************************

 0000                 ROM:        EQU  0      ; BEGINING OF ROM MEMORY
 FF00                 RAM:        EQU  0FF00H; BEGINING OF RAM MEMORY
 005A                 FULLYOFF:   EQU  90     ; VREF VALUE FOR FULLY OFF CHOPPER
 00FA                 FULLYON:    EQU  250    ; VREF VALUE FOR FULLY ON CHOPPER
 00FF                 UP:         EQU  0FFH   ; PERTURBATION FLAGS FOR UP
 0000                 DOWN:       EQU  0      ; AND DOWN PERTURBATION
 0087                 VBATMAX:    EQU  135    ; THE VOLTAGE WHERE PANELS WILL BE OFF
 0072                 VBATMIN:    EQU  114    ; THE VOLTAGE WHERE GENERATOR WILL BE STARTED
 0084                 VBATGOF:    EQU  132    ; GENERATOR STOPPING VOLTAGE
 0044                 STCONS1:    EQU  68     ; THIS VALUE WILL BE COMPARED WITH THE GENERATOR

                                              ; VOLTAGE TO DETERMINE  IF IT IS STARTED OR NOT
 0007                 TMAX:       EQU  7      ; THIS IS THE MAXIMUM DURATION FOR THE STARTER
                                              ; MOTOR OF THE GENERATOR WILL BE ON
                      ;
```

```
                            ;-------------------------------------------------------------------
FF00                                    ORG  RAM
FF00                        TIME:       DS   1     ; A COUNTER FOR START TIMING
FF01                        TRY:        DS   1     ; A COUNTER FOR THE NUMBER OF TIMES THE M/C IS STARTE
FF02                        CHORKE:     DS   1     ; A FLAG TO INDICATE CHORKE POSITION 00/FF=OFF/ON
FF03                        OLDPOWER:   DS   2     ; POWER VALUE OF THE PREVIOUS ITERATION
FF05                        NEWPOWER:   DS   2     ; POWER VALUE OF THE LAST ITERATION
FF07                        VREF:       DS   1     ; THE REFFERANCE VOLTAGE FOR THE CHOPPER OSCILATOR
FF08                        VREFMAX:    DS   1     ; THE REFERANCE VALUE WHERE THE MAXIMUM POWER
                                                   ; IS OBTAINED
FF09                        DISTFLAG:   DS   1     ; A FALG TO INDICATE THE DIRECTION OF THE NEXT
                                                   ; STEP OF THE PERTURBATION
FF0A                        MAXPOWER:   DS   2
FF0C                        MAXVREF:    DS   1
FF0D                        MAXTEMP:    DS   2     ; A TEMPORARY STORAGE FOR THE INITIAL SWEEP
                            ;
                            ;-------------------------------------------------------------------
0000                                    ORG  ROM
0000  BA                    RESET:      DI               ; BEGINING OF THE INITIALISATION
0001  04 FF FF                          LXI  SP,0FFFFH   ; INITIALIZE STACK POINTER TO END OF RAM
0004  69 0F                             MVI  A,0FH       ; SET MEMORY MAPPING REGISTER FOR
0006  4D D0                             MOV  MM,A        ; 64K BYTES MEMORY CONFIGURATION
0008  69 00                             MVI  A,0         ;
000A  4D D2                             MOV  MA,A        ; SET PORT A TO OUTPUT MODE
000C  4D D3                             MOV  MB,A        ; SET PORT B TO OUTPUT MODE
000E  69 00                             MVI  A,0
0010  4D C8                             MOV  ANM,A       ; SET A/D CONVERTERS FOR SCAN MODE
0012  69 FF                             MVI  A,0FFH      ; MUSK INTERRUP MUSK REGISTER
```

```
0014  4D C7                       MOV  MKL,A      ; LOW AND
0016  4D C6                       MOV  MKH,A      ; HIGH PORTIONS
0018  68 FF                       MVI  V,0FFH     ; SET WORKING REGISTER TO BEGINING OF RAM
001A  64 01 FC                    MVI  PB,0FCH    ; END OF INITIALISATION OF PROCESSOR
001D  64 00 5A     INISWEEP:      MVI  PA,FULLYOFF
0020  40 CC 00                    CALL LATCHEN
0023  69 5A                       MVI  A,FULLYOFF
0025  63 07                       STAW VREF\256
0027  63 08                       STAW VREFMAX\256
0029  6E 00                       MVI  H,0
002B  6F 00                       MVI  L,0
002D  70 3E 03 FF                 SHLD OLDPOWER
0031  70 3E 05 FF                 SHLD NEWPOWER
0035  70 3E 0A FF                 SHLD MAXPOWER
0039  70 3E 0D FF                 SHLD MAXTEMP
003D  71 09 FF                    MVIW DISTFLAG\256,UP
0040  20 07        BEGSWEEP:      INRW VREF\256
0042  40 B8 01                        CALL DELAY2
0045  75 07 FA                    EQIW VREF\256,FULLYON
0048  C9                          JR   CALCPOWER
0049  01 0C                       LDAW MAXVREF\256
004B  4D C0                       MOV  PA,A
004D  40 CC 00                    CALL LATCHEN
0050  4E 22                       JRE  MAINEXE
0052  4C E0        CALCPOWER:     MOV  A,CR0
0054  1A                          MOV  B,A
0055  4C E1                       MOV  A,CR1
```

```
0057  48 2E                          MUL  B          ;POWER IN EA
0059  B7                             DMOV H,EA
005A  70 3E 0D FF                    SHLD MAXTEMP
005E  70 3F 0A FF                    LHLD MAXPOWER
0062  74 B7                          DSUBNB EA,H    ;SKIP IF NO BARROW
0064  4F DA                          JRE  BEGSWEEP
0066  70 3F 0D FF                    LHLD MAXTEMP
006A  70 3E 0A FF                    SHLD MAXPOWER
006E  01 07                          LDAW VREF\256
0070  63 0C                          STAW MAXVREF\256
0072  4F CC                          JRE  BEGSWEEP
                  ;
                  ;****************************************
                  ;***  BEGINING OF MAIN EXECUTION LOOP ***
                  ;****************************************
                  ;
0074  4C E2       MAINEXE:           MOV  A,CR2        ; READ THE BATT VOLTAGE
0076  37 87                          LTI  A,VBATMAX    ; IF IT IS NOT LESS THAN THE MAX BATT VOLTAGE
0078  40 D9 00                       CALL FLOATCHMD    ; THEN CALL THE FLOAT CHARGE SUBROUTINE
007B  4C E2                          MOV  A,CR2        ; IF THE BATTERY VOLTAGE IS LESS THEN OR EQUAL
007D  27 72                          GTI  A,VBATMIN    ; TO MIN BATTERY VOLTAGE THEN CALL THE
007F  40 02 01                       CALL GENCHMD      ; GENERATOR CHARGE SUBROUTINE
0082  01 09       DISTURB:           LDAW DISTFLAG\256 ; READ THE DIRECTION OF THE PERTURBATION
0084  77 FF                          EQI  A,UP         ; IS IT UP?
0086  D0                             JR   DOWNL        ; IF NOT THEN JUMP TO DOWNL
0087  75 07 FA    UPL:               EQIW VREF\256,FULLYON  ; DIRECTION IS UP BUT VREF = FULLYON ?
008A  C2                             JR   NFON         ; IF NOT THEN IT CAN BE INCREMENTED
008B  4E 2E                          JRE  NEGATIVE     ; BUT IF IT IS EQUAL TO FULLYON THEN REVERSE
```

```
008D  20 07         NFON:      INRW VREF\256     ; THE DIRECTION OF THE PERTURBATION
008F  01 07                    LDAW VREF\256     ; STORE THE NEW VREF AND
0091  4D C0                    MOV  PA,A         ; SEND IT TO THE D/A LATCH
0093  40 CC 00                 CALL LATCHEN      ; SEND AN ENABLE PULSE
0096  CF                       JR   CALCUPOW     ; CALCULATE THE POWER VALUE FOR THE NEXT ITER
0097  75 07 5A      DOWNL:     EQIW VREF\256,FULLYOFF ; DIRECTION IS DOWN BUT VREF = FULLYOFF ?
009A  C2                       JR   NFOFF        ; IF NOT THEN IT CAN BE DECREMENTED
009B  4E 1E         *          JRE  NEGATIVE     ; BUT IF IT IS EQUAL TO FULLYOFF THEN REVERSE
009D  30 07         NFOFF:     DCRW VREF\256     ; THE DIRECTION OF THE PERTURBATION
009F  01 07                    LDAW VREF\256     ; STORE THE NEW VREF AND
00A1  4D C0                    MOV  PA,A         ; SEND IT TO PORT A FOR D/A LATCH
00A3  40 CC 00                 CALL LATCHEN      ; SEND AN ENABLE PULSE
00A6  4C E0         CALCUPOW:  MOV  A,CR0        ; FOR CALCULATING THE PANEL POWER FIRST READ
                                                 ; THE PANEL VOLTAGE
00A8  1A                       MOV  B,A          ; AND STORE IT IN B REGISTER
00A9  4C E1                    MOV  A,CR1        ; SECONDLY READ THE PANEL CURRENT INTO A REG
00AB  48 2E                    MUL  B            ; MULTIPLY A AND B REGISTERS TO OBTAIN THE
                                                 ; PANEL POWER. THE RESULT IS STORED IN EA REG
00AD  B7                       DMOV H,EA         ; STORE THE POWER IN HL REGISTER PAIR
00AE  70 3E 05 FF              SHLD NEWPOWER     ; STORE IT ALSO TO RAM IN VARIABLE NEWPOWER
00B2  70 3F 03 FF              LHLD OLDPOWER     ; LOAD HL WITH THE PREVIOUS VALUE OF THE POWER
00B6  74 B7                    DSUBNB EA,H       ; SUBTRACT OLDPOWER FROM NEWPOWER
00B8  C2                       JR   NEGATIVE     ; IF THE RESULT IS NEGATIVE i.e.
                                                 ; OLDPOWER > NEWPOWER THEN
00B9  4F C7                    JRE  DISTURB      ; REVERSE THE DIRECTION OF THE PERTURBATION
00BB  40 C0 00      NEGATIVE:  CALL INVERTFLAG   ; DIRECTION FLAG IS INVERTED
00BE  4F B4                    JRE  MAINEXE      ; SINCE THIS IS A DO FOREVER TYPE OF LOOP
```

```
                                                    ; AT THE END IT RETURNS TO THE BEGINING
                              ;
                              ;***************************************
                              ;***    END OF MAIN EXECUTION LOOP   ***
                              ;***************************************
                              ;
                              ;---------------------------------------------------------------------
                              ;
                              ;             TAKES THE COMPLEMENT OF THE DISTURBANCE FLAG
                              ;
00C0  75 09 FF                INVERTFLAG:   EQIW DISTFLAG\256,UP
00C3  C4                                    JR   NOTUP
00C4  71 09 00                              MVIW DISTFLAG\256,DOWN
00C7  B8                                    RET
00C8  71 09 FF                NOTUP:        MVIW DISTFLAG\256,UP
00CB  B8                                    RET
                              ;
                              ;---------------------------------------------------------------------
                              ;
                              ;             SENDS AN ENABLE PULSE (ACTIVE HIGH) TO D/A LATCH
                              ;
00CC  4C C1                   LATCHEN:      MOV  A,PB
00CE  17 01                                 ORI  A,1
00D0  4D C1                                 MOV  PB,A
00D2  B1                                    PUSH B
00D3  A1                                    POP  B
00D4  07 FE                                 ANI  A,0FEH
00D6  4D C1                                 MOV  PB,A
```

```
00D8  B8                          RET
                      ;
                      ;--------------------------------------------------------------------
                      ;
                      ;           KEEPS THE BATTERY VOLTAGE AT VBATMAX AND IF IT DROPS
                      ;           RETURNS CONTROL TO MPPT ALGORITHM
                      ;
00D9  4C E2           FLOATCHMD:  MOV  A,CR2        ; READ THE BATT VOLTAGE
00DB  27 87                       GTI  A,VBATMAX
00DD  D1                          JR   BATLOW
00DE  01 07                       LDAW VREF\256
00E0  27 5A                       GTI  A,FULLYOFF
00E2  C3                          JR   BEKLE
00E3  51                          DCR  A
00E4  63 07                       STAW VREF\256
00E6  4D C0           BEKLE:      MOV  PA,A
00E8  40 CC 00                    CALL LATCHEN
00EB  40 B8 01                    CALL DELAY2
00EE  EA                          JR   FLOATCHMD
00EF  01 07           BATLOW:     LDAW VREF\256
00F1  77 FA                       EQI  A,FULLYON
00F3  C1                          JR   BTLW
00F4  B8                          RET
00F5  41              BTLW:       INR  A
00F6  63 07                       STAW VREF\256
00F8  4D C0                       MOV  PA,A
00FA  40 CC 00                    CALL LATCHEN
```

```
00FD  40 B8 01                      CALL DELAY2
0100  4F D7                         JRE  FLOATCHMD

                      ;
                      ;-------------------------------------------------------------------
                      ;
                      ;             WHEN THE BATTERY VOLTAGE IS DROP BELOW A CERTAIN VALUE
                      ;             DEFINED BY THE VBATMIN CONSTANT THIS SUBROUTINE IS CALLED
                      ;             BY THE MAIN EXECUTION LOOP. THIS SUBROUTINE STARTS THE
                      ;             GENERATOR DRIVEN BY A GASOLINE MOTOR AND IF NECESSARY IT
                      ;             ACTIVATES THE ELECRICALLY DRIVEN CHOKE. THE GENERATOR REMAINS
                      ;             RUNNING UNTIL THE BATTERY VOLTAGE REACHES TO THE VALUE
                      ;             DEFINED BY VBATGOF SYSTEM CONSTANT., WHEN THIS VOLTAGE IS
                      ;             REACHED THE GENERATOR IS STOPPED AND THE CONTROL RETURNS
                      ;             TO THE MAIN EXECUTION LOOP.
                      ;
0102  71 02 00        GENCHMD:      MVIW CHORKE\256,0 ; AT FIRST ASSUME M/C IS HOT AND TRY TO
                      ;                                 START THE M/C WHILE CHOKE IS PASSIVE
0105  71 01 00                      MVIW TRY\256,0    ; THIS COUNTER KEEPS HOW MANY TIMES THE M/C
                      ;                                 IS TRIED TO BE STARTED
0108  64 01 F8        START:        MVI  PB,0F8H      ; START TO LOW
010B  71 00 00                      MVIW TIME\256,0   ; THIS COUNTER KEEPS THE TIME THAT THE
                                                      ; STARTER MOTOR OF THE GASOLINE MOTOR IS
                                                      ; KEPT RUNING. IF THIS TIME IS ELLEPSED
                                                      ; WITHOUT SUCCESFULLY STARTING THE MACHINE
                                                      ; THEN IT WILL BE STOPED AND A DELAY WILL BE
                                                      ; GIVEN BEFORE THE NEXT TRY
010E  4C E3           AK:           MOV  A,CR3        ; READ THE GEN VOLTAGE
```

```
0110  27 44                  GTI  A,STCONS1   ; AND COMPARE IT WITH THIS STARTING CONSTANT
0112  4E 15        *         JRE  SN          ; IF IT EXCEEDS THIS CONSTANT THAN THIS MEANS
                                              ; THAT THE M/C IS SUCCESFULLY STARTED AND
                                              ; THE STARTER MOTOR MUST BE STOPED IMMEDIATELY
0114  64 01 F4               MVI  PB,0F4H     ; RUN TO LOW. THIS CAUSES THE STARTER MOTOR
                                              ; TO BE STOPED.
0117  40 A5 01               CALL DELAY       ; NOW WAIT 1 SEC. FOR THE M/C TO REACH
011A  40 A5 01               CALL DELAY       ; STEADY STATE OPERATING CONDITIONS
011D  4C E2        LB:       MOV  A,CR2       ; READ THE BATTERY VOLTAGE AND COMPARE IT
011F  27 84                  GTI  A,VBATGOF   ; WITH THE VBATGOF CONSTANT.
0121  FB                     JR   LB          ; WAIT UNTIL BATT VOLTAGE RISES
0122  64 01 FC               MVI  PB,0FCH     ; THAN TURN THE GENERATOR OFF
0125  40 99 01               CALL AKI         ; WAIT FOR 5 SEC FOR GENERATOR TO STOP
0128  B8                     RET              ; AND RETURN CONTROL TO THE MAIN EXECUTION LOO
0129  20 00        SN:       INRW TIME\256    ; BUT IF THE GENERATOR VOLTAGE DOES NOT
                                              ; RISE UP TO THE STARTING CONSTANT VALUE
012B  40 A5 01               CALL DELAY       ; TIME COUNTER IS INCREMENTED UNTIL IT REACHES
012E  01 00                  LDAW TIME\256    ; TO THE TMAX VALUE
0130  27 07                  GTI  A,TMAX      ; IF THIS TIME LIMIT DEFINED BY TMAX IS
0132  4F DA                  JRE  AK          ; EXCEEDED THE STARTER MOTOR IS STOPED.
0134  64 01 FC               MVI  PB,0FCH     ; RUN TO HIGH (STARTER MOTOR STOP)
0137  20 01                  INRW TRY\256     ; THE COUNTER USED FOR HOW MANY TIMES THE M/C
                                              ; IS TRIED TO BE STARTED IS INCREMENTED AND
0139  01 01                  LDAW TRY\256     ; THE NEW VALUE IS STORED
013B  37 02                  LTI  A,2         ; COMPARE THIS NUMBER BY 2 i.e TRY 2 TIMES
013D  C5                     JR   CHOR        ; AT THE END OF 2ND TRY IF THE M/C IS NOT
                                              ; STARTED SUCCESFULLY ASSUME M/C IS COOL
```

```
                                           ; AND TRY CHOKED STARTING ALGORITHM
013E  40 99 01                CALL AKI     ; IF IT WAS THE FIRST TRY THEN DELAY FOR
                                           ; 5 SEC
0141  4F C5                   JRE  START   ; THAN TRY TO START AGAIN
0143  71 02 FF     CHOR:      MVIW CHORKE\256,0FFH  ;ASSUME M/C IS COOL NOW AND TRY AGAIN
                                           ; WHILE CHOKE IS ACTIVE
0146  40 99 01                CALL AKI     ; DELAY FOR 5 SEC
0149  71 01 00                MVIW TRY\256,0   ; RESET THE TRY COUNTER
014C  64 01 E8     STARTCK:   MVI  PB,0E8H ; CHORKE ON,START ON
014F  71 00 00                MVIW TIME\256,0  ; RESET THE TIME COUNTER
0152  4C E3        AKCK:      MOV  A,CR3   ; READ THE GEN VOLTAGE AND COMPARE IT WITH
0154  27 32                   GTI  A,50    ; THE STARTING CONSTANT FOR CHORKED START
0156  4E 21                   JRE  SNCK    ; IF THE M/C IS STARTED (GENERATOR VOLTAGE
                                           ; IS GREATHER THAN THE STARTING CONSTANT)
0158  64 01 E4                MVI  PB,0E4H ; THAN STOP THE STARTER MOTOR BUT KEEP THE
015B  40 A5 01                CALL DELAY   ; CHOKE ACTIVE FOR ONE SECOND
015E  40 A5 01                CALL DELAY
0161  40 A5 01                CALL DELAY   ; DELAY FOR ONE SECOND
0164  64 01 F4                MVI  PB,0F4H ; CHORKE OFF
0167  40 A5 01                CALL DELAY   ; DELAY 1/2 SEC
016A  40 A5 01                CALL DELAY
016D  4C E2        LBCK:      MOV  A,CR2   ; READ THE BATT VOLTAGE
016F  27 84                   GTI  A,VBATGOF   ; AND COMPARE IT WITH VBATGOF CONSTANT
0171  FB                      JR   LBCK    ; WAIT UNTIL BATTERY VOLTAGE RISES
0172  64 01 FC                MVI  PB,0FCH ; THAN TURN THE GENERATOR OFF
0175  40 99 01                CALL AKI     ; WAIT FOR 5 SEC FOR THE GENERATOR TO STOP AND
0178  B8                      RET          ; RETURN CONTROL TO MAIN EXECUTION LOOP
0179  20 00        SNCK:      INRW TIME\256    ; BUT IF THE GENERATOR VOLTAGE DOES NOT
```

```
017B  40 A5 01                 CALL DELAY      ; RISE UP TO THE STARTING CONSTANT VALUE
017E  01 00                    LDAW TIME\256   ; TIME COUNTER IS INCREMENTED UNTIL IT REACHES
0180  27 0C                    GTI  A,12       ; TO THE TMAX VALUE
0182  4F CE                    JRE  AKCK       ; IF THIS TIME LIMIT IS EXCEEDED THE STARTER
0184  64 01 EF                 MVI  PB,0EFH    ; MOTOR IS STOPED
0187  20 01                    INRW TRY\256    ; THE TRY COUNTER IS INCREMENTED AND
0189  01 01                    LDAW TRY\256    ; THE NEWE VALUE IS STORED
018B  37 03                    LTI  A,3        ; TRY 3 TIMES
018D  C5                       JR   STOP       ; IF THE M/C DOES NOT START AND THE TRY COUNTE
                                               ; IS LESS THAN 3 , THAN TRY TO START IT AGAIN
018E  40 99 01                 CALL AKI        ; AFTER A 5 SEC DELAY
0191  4F B9                    JRE STARTCK     ; BUT IF IT DOES NOT START AFTER 3RD TRY THAN
0193  64 01 DC      STOP:      MVI  PB,0DCH    ; GIVE AN ERROR LED SIGNAL
0196  00                       NOP             ; AND STOP IN THIS ENDLESS LOOP!..
0197  00                       NOP
0198  FA                       JR   STOP
0199  6A 00         AKI:       MVI  B,0        ; THIS IS A SUBROUTINE
019B  40 A5 01      LB2:       CALL DELAY      ; FOR 5 SEC DELAY
019E  42                       INR  B          ; IT CALLS DELAY SUBROUTINE
019F  69 0C                    MVI  A,12       ; FOR 12 TIMES
01A1  60 2A                    GTA  B,A
01A3  F7                       JR   LB2
01A4  B8                       RET
01A5  B1            DELAY:     PUSH B          ; THIS SUBROUTINE GIVES 450 msec
01A6  6A 00                    MVI  B,0        ; DELAY FOR THE CURRENT CLOCK FREQUENCY
01A8  42            B2:        INR  B          ; BEGINING OF THE OUTER LOOP
01A9  6B 00                    MVI  C,0
```

```
01AB  43        B1:       INR  C        ; BEGINING OF THE INNER LOOP
01AC  69 F0               MVI  A,0F0H
01AE  60 2B               GTA  C,A
01B0  FA                  JR   B1       ; END OF INNER LOOP
01B1  69 F0               MVI  A,0F0H
01B3  60 2A               GTA  B,A
01B5  F2                  JR   B2       ; END OF OUTER LOOP
01B6  A1                  POP  B        ; RESTORE THE PREVIOUS VALUE OF BC
01B7  B8                  RET           ; REGISTER PAIR FROM THE STACK
01B8  B1        DELAY2:   PUSH B        ; THIS SUBROUTINE GIVES 2 MSEC DELAY
01B9  6A 00               MVI  B,0      ; RESET DELAY COUNTER
01BB  42        BLL:      INR  B        ; INCREMENT THE DELAY COUNTER
01BC  69 F0               MVI  A,0F0H   ; COMPARE IT BY F0
01BE  60 2A               GTA  B,A
01C0  FA                  JR   BLL      ; END OF DELAY LOOP
01C1  A1                  POP  B        ; RESTORE B REG
01C2  B8                  RET
                          END
```

**** Symbol Table ****

AK	010E	AKCK	0152	AKI	0199
B1	01AB	B2	01A8	BATLOW	00EF
BEGSWEEP	0040	BEKLE	00E6	BLL	01BB
BTLW	00F5	CALCPOWER	0052	CALCUPOW	00A6
CHOR	0143	CHORKE	FF02	DELAY	01A5
DELAY2	01B8	DISTFLAG	FF09	DISTURB	0082

DOWN	0000	DOWNL	0097	FLOATCHMD	00D9
FULLYOFF	005A	FULLYON	00FA	GENCHMD	0102
INISWEEP	001D	INVERTFLAG	00C0	LATCHEN	00CC
LB	011D	LB2	019B	LBCK	016D
MAINEXE	0074	MAXPOWER	FF0A	MAXTEMP	FF0D
MAXVREF	FF0C	NEGATIVE	00BB	NEWPOWER	FF05
NFOFF	009D	NFON	008D	NOTUP	00C8
OLDPOWER	FF03	RAM	FF00	RESET	0000
ROM	0000	SN	0129	SNCK	0179
START	0108	STARTCK	014C	STCONS1	0044
STOP	0193	TIME	FF00	TMAX	0007
TRY	FF01	UP	00FF	UPL	0087
VBATGOF	0084	VBATMAX	0087	VBATMIN	0072
VREF	FF07	VREFMAX	FF08		

**** End of Symbol Table ****