British Journal of Applied Science & Technology
2(3): 275-295, 2012

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Development of an Intelligent Electronic Module for Energy Management in Wind/Diesel or Photovoltaic/Diesel Hybrid Systems

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Authors' contributions

This work was carried out in collaboration between all authors. TJK designed the study, wrote the protocol, fabricated the wind turbine and organized the field test layout. PT and HF did the computer programming, simulation and soldering of electronic parts. AF supervised and directed the research. TJK and PT wrote the first draft of the manuscript. All authors participated in the field tests and in literature searches. All authors read and approved the final manuscript.

Research Article

Received 26th April 2012
Accepted 19th July 2012
Online Ready 25th July 2012

ABSTRACT

An intelligent electronic module for managing battery power in a wind/diesel, solar/diesel or wind/solar/diesel hybrid systems was designed, fabricated and tested. It is made of five blocks mainly a power supply unit, a battery voltage monitor, a programmable interface controller, a battery charger, and a start up monitor block. A computer program inscribed on the module permits it to perform five commands. It connects dump load 1 when battery voltage attains 15V. It connects dump load 2 when battery voltage of 15V persists for some time while dump load 1 is already connected. It starts the backup generator when battery voltage is below 10.5V with no energy from the renewable source. It is also programmed to activate battery charging when only the generator is working. Based on the logical sequence designed, the module was erected on an integrated circuit using the, Advanced Routing and Editing Software, (ARES) of Proteus Professional Laboratory. Simulations using the Isis software for all types of eminent energy hybrid system scenarios in an off grid setting revealed that the module can successfully manage energy

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supply in a wind/diesel, PV/diesel or wind/PV/diesel system. During field tests the module was inserted in a micro hybrid system made of a small locally made 700watts Hugh Piggott type wind turbine, a 200watts solar module and a 5kw diesel generator. The battery bank was a 2400AH battery bank capacity. The module successful communicated with the all the components connected except dump load 2 due to the fact that dump load one was enough to handle excess voltage. It was concluded that the module can successful manage energy storage and distribution in a small off grid hybrid system of wind/diesel of PV/diesel.

Keywords: Renewable energy systems; charge controller; intelligent energy management; energy efficiency; solar energy; wind energy.

1. INTRODUCTION

The global energy crises occasioned by the gradual increase in world population, climate change and the need for cleaner productions have generated much interest on renewable energy sources. The need for renewable energy resources has taken centre stage in the quest for energy for domestic and industrial applications. These resources are gradually being preferred because of their relatively less polluting effect when compared to fossil fuels and the fact that their exploitation can help slow down the rate of global warming. There are now many ways of producing energy in general and electricity in particular from renewable resources including solar, wind, hydro, thermal and biomass just to mention a few. The major problem often encountered is the efficient management of this energy especially from stochastic sources such as wind and solar when they are combined with other sources like backup batteries, diesel generators and grid systems. Many renewable energy companies cannot sell their products because potential customers do not have a guarantee of proper management of the energy during the idle period of the renewable energy facility. Many governments would like to invest in solar energy but the intermittent nature of the supply and the lack of convincing management strategies often discourage top management from choosing this option.

The combination of many sources of energy optimises energy supply in a given network especially when such energy supply is produced from unsteady sources. There are many of such combinations that can be possible including wind diesel, (Hrayshat, 2009; Magnusson, 1982; Tomilson et al., 1997; Harrap and Baird, 1987; Belhamel et al., 2002; Lipman, 2002), photovoltaic-diesel (Manasse, 1980) and wind photovoltaic diesel (Todd, 1987; Akerlund, 1983; Hennet and Samarakou, 1986). In independent stand alone off grid systems, combined energy systems are becoming very common, so that one can take the relay when environmental conditions cannot ensure the efficient functioning of the other system.

The optimisation of energy supply from a hybrid system coupled with electrochemical storage, with or without diesel back up, depends on the efficiency of each of the sub-systems and on the efficiency of battery bank power management. Although other systems exist for storing energy including Hydrogen production and utilisation (Belhamel et al., 2002; Beyer et al., 2002), these are not yet common especially in developing countries. The advantage of hybrid systems lies on the ability to store and manage the energy produced in order to supply during times of black out, or idle time of the energy producing facility. A complete stand alone hybrid system must protect the battery bank against serious charging and discharging currents. The battery bank is usually the most expensive unit in many hybrid systems and improper charging and discharging processes can damage the bank within a very short time because irreversible destructive reactions occur in the battery bank. Proper energy management in a hybrid system economises fuel used in the backup generator and also prolongs battery life. Proper sizing and management are therefore very essential (Zamani and Riahy, 2009; Koussa et al., 2002). In such systems, energy from the wind turbine or the solar system is directed to the charge controller which charges the battery when battery voltage is less than 12 volts or 24 volts depending on the voltage rating of the system. The controller has a utility line which is kept live so far as battery voltage is above 10.5V. When battery voltage gets to above 14.5V a second relay sends power to another utility line called the dump to avoid over charging of the battery bank.

Many modules for battery power management in hybrid systems or charge controllers have been designed and developed and are commercially available. However, charge controllers are not designed and constructed to ensure energy management in the whole hybrid system. The management of hybrid system is complicated. In almost all the cases, the charge controller is the major instrument. It cuts off power supply to utility lines when the battery voltage reaches the lower critical level (of 10.5V for 12 volts systems), and it diverts the charging current to a dump load when battery voltage reaches the upper critical level 14.5V for a 12 volts battery system. In an attempt to optimise the battery protection, many commercially available charge controllers are used in pairs, one to protect the battery against over charge and another to protect the battery against over discharge. The use of two controllers increases the cost of installation further prolonging the payback period of the investment. Also, supply of energy from the battery bank still relies on human effort for proper and efficient management (Manwell et al., 2002). Fig. 1 shows an energy management system that has a backup generator.

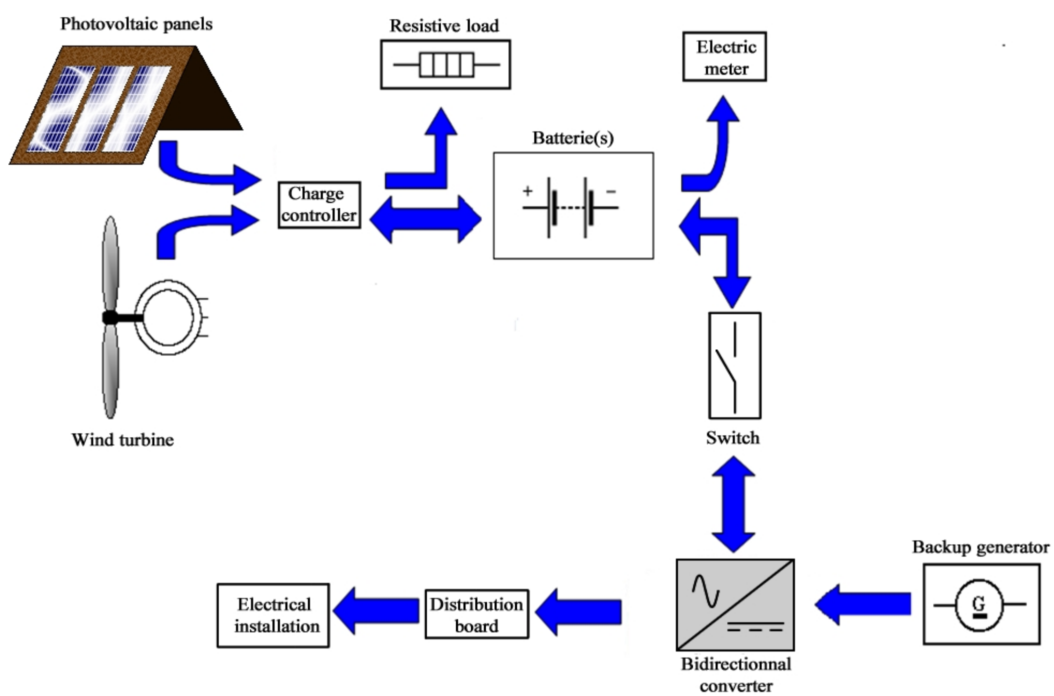

Fig. 1. Typical layout of a wind photovoltaic/diesel backup systems

In such systems, an automatic generator switch has to be installed to start up the backup generator when battery voltage is low, otherwise meaning that there is no energy supply from the stochastic renewable source.

The independent monitoring and management of these activities by different electrical/electronic equipment, call for extra investment. It also increases the risks of failure and makes trouble shooting difficult. Most modules available in the market do not arrange for the battery bank to be charged when the backup generator is operating. It is important to develop modules that do not only control battery charging, but also properly control other indispensible activities in the hybrid stem like putting on and off the generator when necessary and ensuring the charging of batteries by the generator.

This research exercise was carried out in order to design, fabricate and test a single intelligent electronic module capable of properly managing battery power in a wind-diesel, photovoltaic-diesel or a wind-photovoltaic-diesel system. The module would protect the battery against overcharge and protect the battery against over discharge. It would automatically connect and disconnect dump loads when necessary. The module also had the responsibility of switching on the generator when the battery voltage is low indicating low or no power supply from renewable energy facility.

2. MATERIALS AND METHODS

The logical layout for the electronic module developed for energy management in hybrid systems is shown on Fig. 2. The wind turbine and the photovoltaic array produce electricity during favourable conditions of appropriate solar radiation and wind speed. The energy source is connected directly to the electronic module which now takes over and automatically manages the energy produced while at the same time protecting the battery bank.

The module was designed to perform the following tasks:

- Protect the battery against excessive over charge
- Protect the battery against excessive discharge
- Start and stop the generator in times of need
- Connect and disconnect dump load when necessary
- Ensure zero blackout as long as the generator is in good functioning conditions and contains fuel
- Allow battery charging when the generator is operational

2.1 Structure and Functioning of the New Architecture for Hybrid Systems

The lead acid batteries used in this research were made of cells having a maximum voltage of 2.1V. Each battery of 12 V rating had six cells. The lower discharge level considered for each cell was taken as 1.8V. This means that a battery of six cells would be considered as discharged when the total voltage reads 10.8V. The lower limit of 10.5 V was assumed. According to Lindsay, 2004, the voltage across one cell must not be more than 2.4V or a total of 14.4 for the whole battery or 14.5 the upper limit. The limits put into the computer program where between 10.5V and 15V.

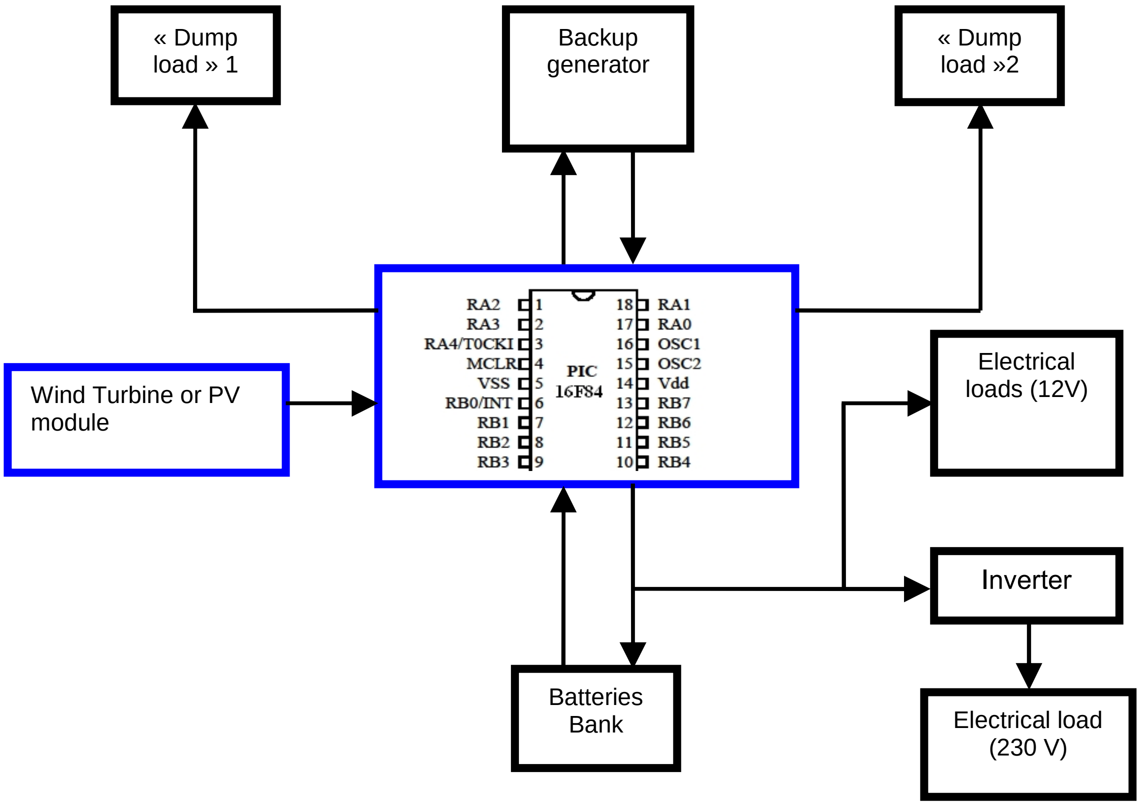

Fig. 2. Synoptic overall layout of the functioning of the intelligent module for energy management in wind diesel/photovoltaic diesel hybrid systems

When battery voltage is lower than 10.5V, the intelligent electronic module starts the generator and then disconnects the utility supply to prevent it from excessive discharge. After the diesel generator is then connected to supply power to the local utility line as well as to the battery for charging. When battery bank voltage is between 10.5V and 15V, the electronic module disconnects the backup generator switching it off, while connecting the battery to the local utility supply line.

When battery voltage is above 15V, the electronic module relays the dump load to spend excessive charge. The dump load can be a water heating element or a high resistance filament lamp. If the voltage of 15V persists for some time, the battery electronic module connects dump load number 2.

2.2 Functional Architecture of the Module

Based on the above mentioned schedule, the electronic module with programmed terms of reference was constructed. Fig. 3 shows the synoptic logic of the module. It is engaged manually using a simple electronic switch. Battery voltage is sensed and then submitted to the required block on the module. The block compares the battery voltage using the external limit of 10.5V and 15V and then sends the appropriate lighting signal through two LED lights located out of the box.

The start-up detector senses the activity of the generator and informs the microcontroller through a numeric signal. The numeric signals obtained from the start-up detector, the battery voltage sensor and the power supply are the input signals of the micro controller which are then used in executing the program. Thus the different outputs of the microcontroller are put into the computer program. The output signals of the microcontroller are then used to attack the interface block responsible for ensuring communication between the module and the other elements of the hybrid energy system.

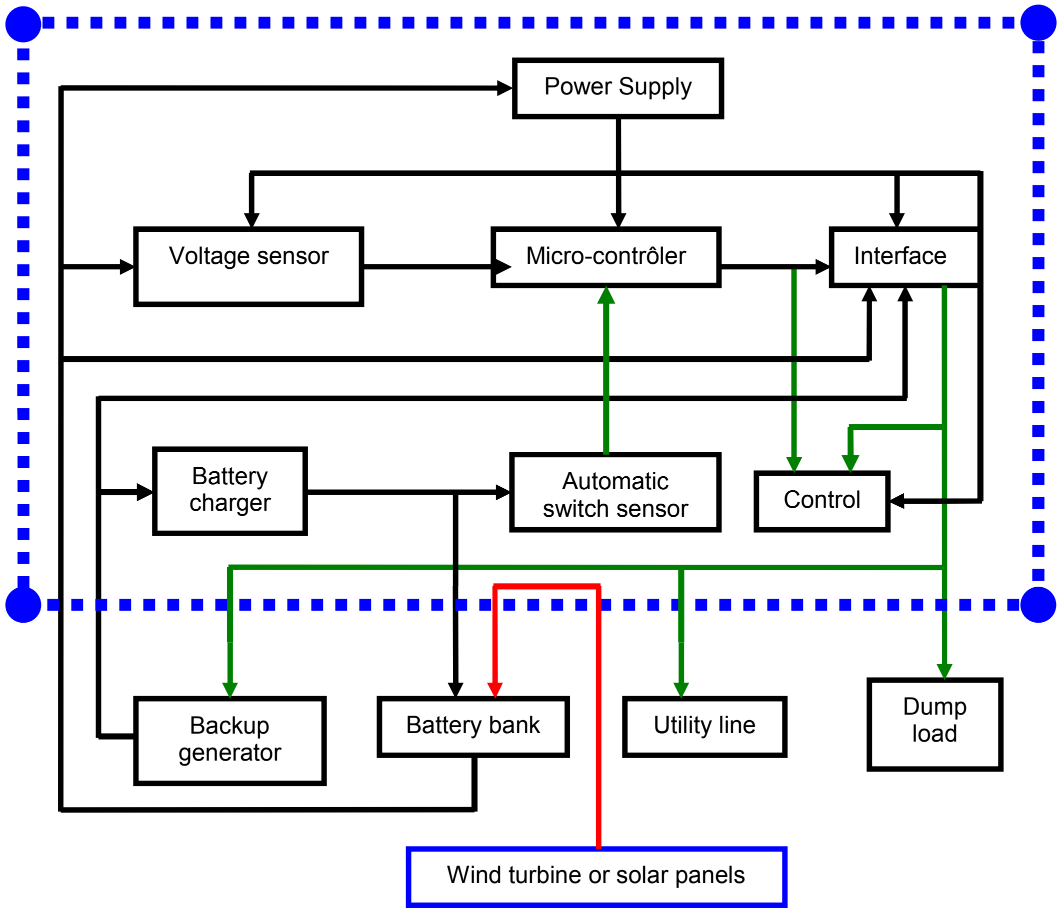

Fig. 3. Synoptic diagram of the controller

2.3. Energy Management by the Module

The microcontroller is the main element in the system responsible for treating the different data sent from the other blocks in the system. The microcontroller used in this work is a PIC16F84 because of its simplicity, its low price, and its capacity to perform all the desired operations the system. In the microcontroller, data are treated and decisions are taken following the algorithm shown on Fig. 4. The decision is then sent to the block interface for application, this ends up in efficient management of the energy produced. The microcontroller was programmed in C Language, and tested using the CCSC program.

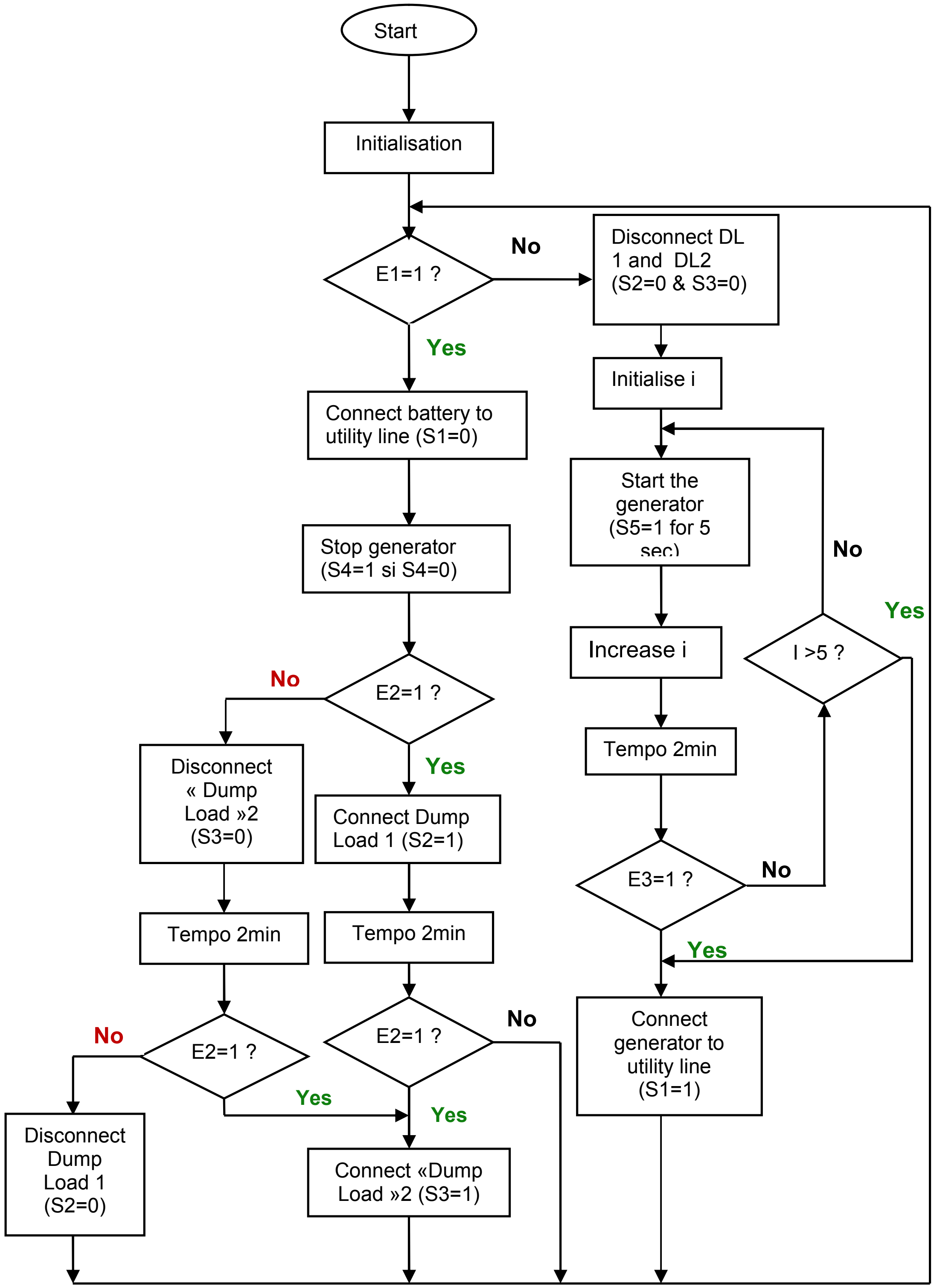

Fig.4. Program algorithm for the electronic module developed

Internal hysteresis was designed into the comparators, to help the comparator avoid oscillation due to small amounts of parasitic feedback. Though sufficient to prevent the comparator from self-oscillating, such internal hysteresis can easily be swamped by any external noise of greater amplitude. Hysteresis effect is taken care of as shown on Fig 4. in our module we used a voltage range comparator based on operational amplifier. The voltage ranges are respectively 10.5V and 15V. However, the start and stop of the diesel generator is controlled by battery voltage being more than or less than 10.5V. To avoid the start and stop effect, a temporization of 2 min is introduced as shown on Fig 4. This will permit the generator to function for at least 2 min when it is started. It is important to note that, this time is defined in the program stored in the micro controller and can therefore be modified according to the type of generator and to the specifications of the hybrid system.

2.4 Electronic Diagram of the System

After careful design and selection of the electronic components the electronic diagram shown on Fig. 5 was developed. The design details and selection procedure of electronic components are available in Tchakoua 2009.

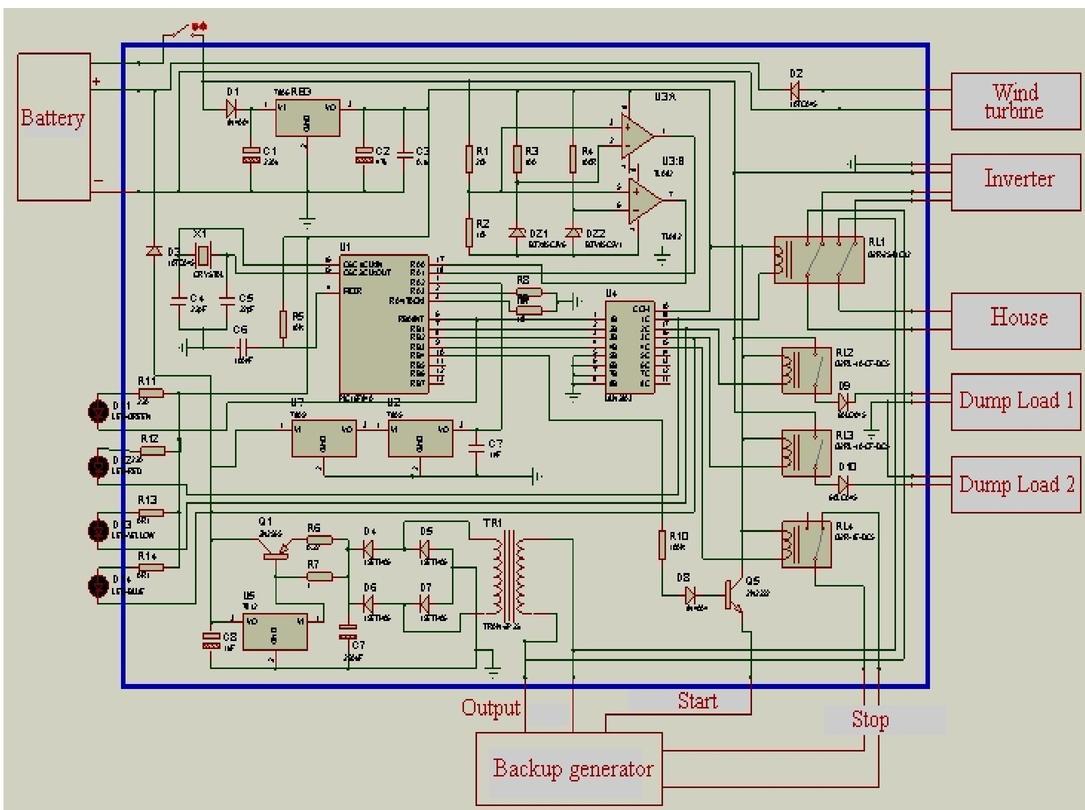

Fig. 5. Electronic diagram of the new module

2.5 Simulation in ISIS

Simulation of the various blocks of the module was done in ISIS software.

2.5.1 Battery simulation

Fig. 6 shows results of simulation of the battery terminal sensor using minimum and maximum values of 10.5V and 15V respectively. As seen on Fig. 6, it uses two comparators U1:A and U1:B with 1.52Volts and 4.46 volts as working voltages.

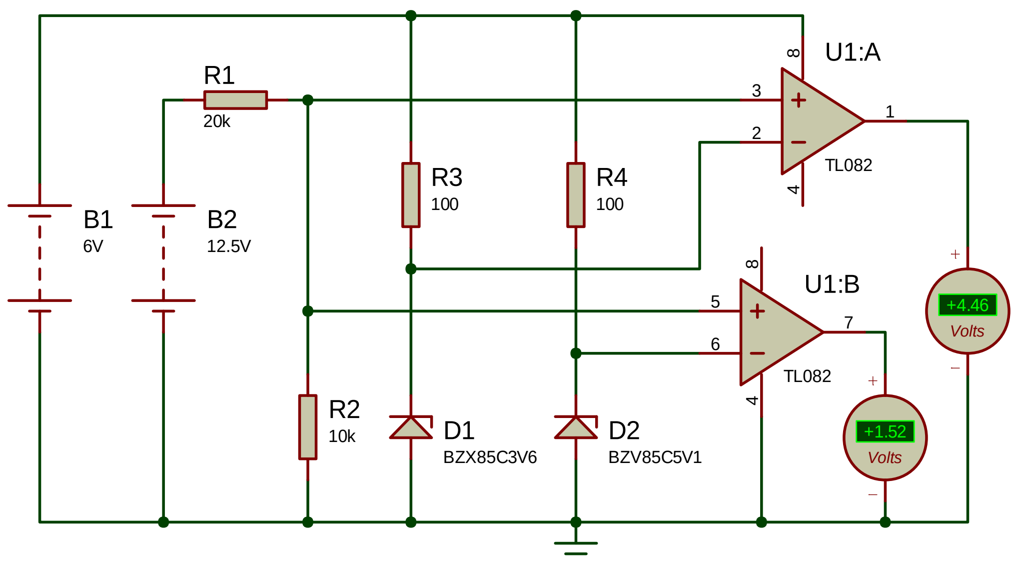

Fig. 6. Simulation of battery terminal monitor in ISIS

2.5.2 Simulation of the power unit

Simulation of the power input unit in ISIS is shown on Fig 7 with a working voltage of 6 Volts. The two capacitors C1 and C2 are to reduce undulation at the entrance and at the exit of regulator respectively.

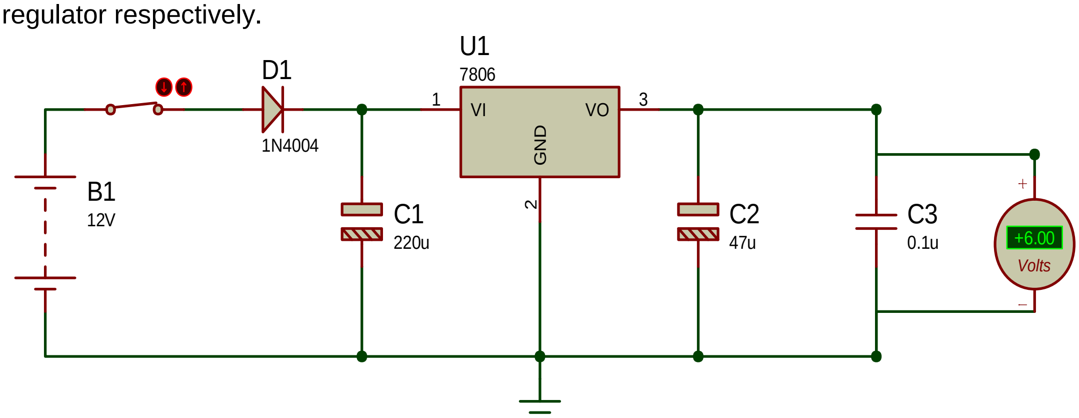

Fig. 7. Simulation of the power input unit in ISIS

2.5.3 Simulation of the battery charger

This can be seen on Fig. 8 with working voltages of 15V, 14.2 and 12 V respectively.
2.5.4 Simulation of the entire electronic module.

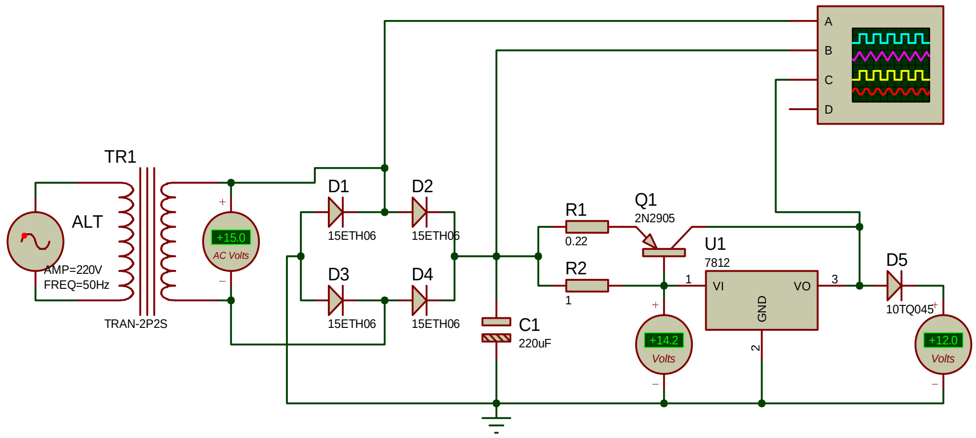

Fig. 8. Simulation of the power unit using ISIS

After combining the five blocks, a simulation of the entire electronic module was realised using ISIS software. Fig. 9 shows the combined total simulation diagram of the electronic module. The description of the various terminals is made in the Table 1.

Table 1. Functions of terminals on the programmable interface

Terminal	Function
RA1	Output of the 10.5V sensor, represented in the program protocol by E1
RA0	Output of the 15V sensor, represented in the program protocol by E2
RA2	Output of the voltage sensor, represented in the program protocol by E3
RB0	Commutation relay command between the battery and le diesel generator
RB1	Dump load 1 connection command switch
RB2	Dump load 2 connection command switch
RB3	Diesel generator switch off command
RB4	Diesel generator switch on command

3. RESULTS AND DISCUSSION

The following results were obtained in simulation in ISIS

3.1 Case 1: Battery Voltage (Vbat) is less than 10.5V (Vbat <10.5V)

The program instructs the generator to start. The result is shown on Fig. 10 (Channel RB4) corresponding to diesel generator switch on command which emits an impulse signal thereby causing the generator to start.

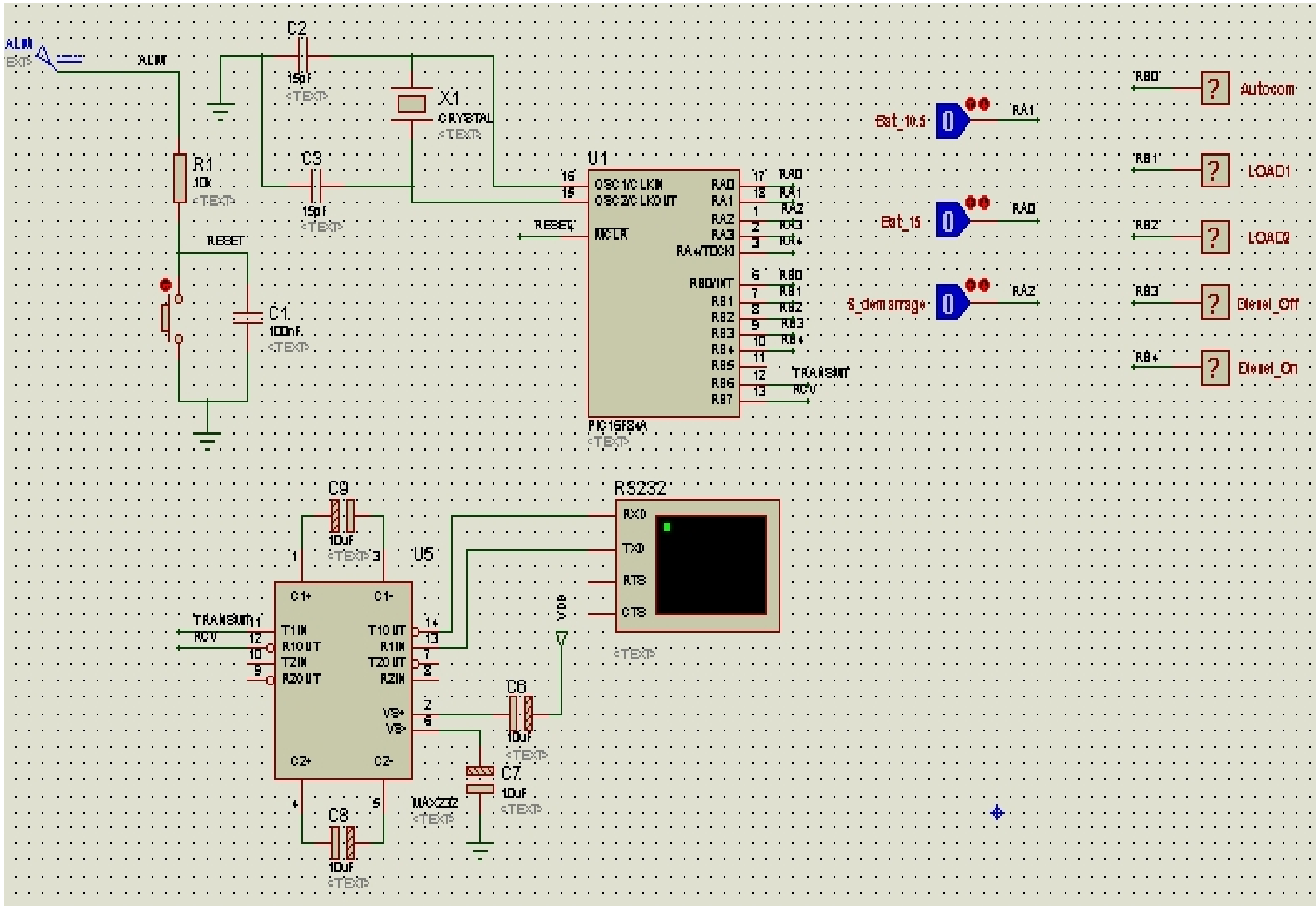

Fig. 9. Combined total simulation diagram of all the five blocks in ISIS

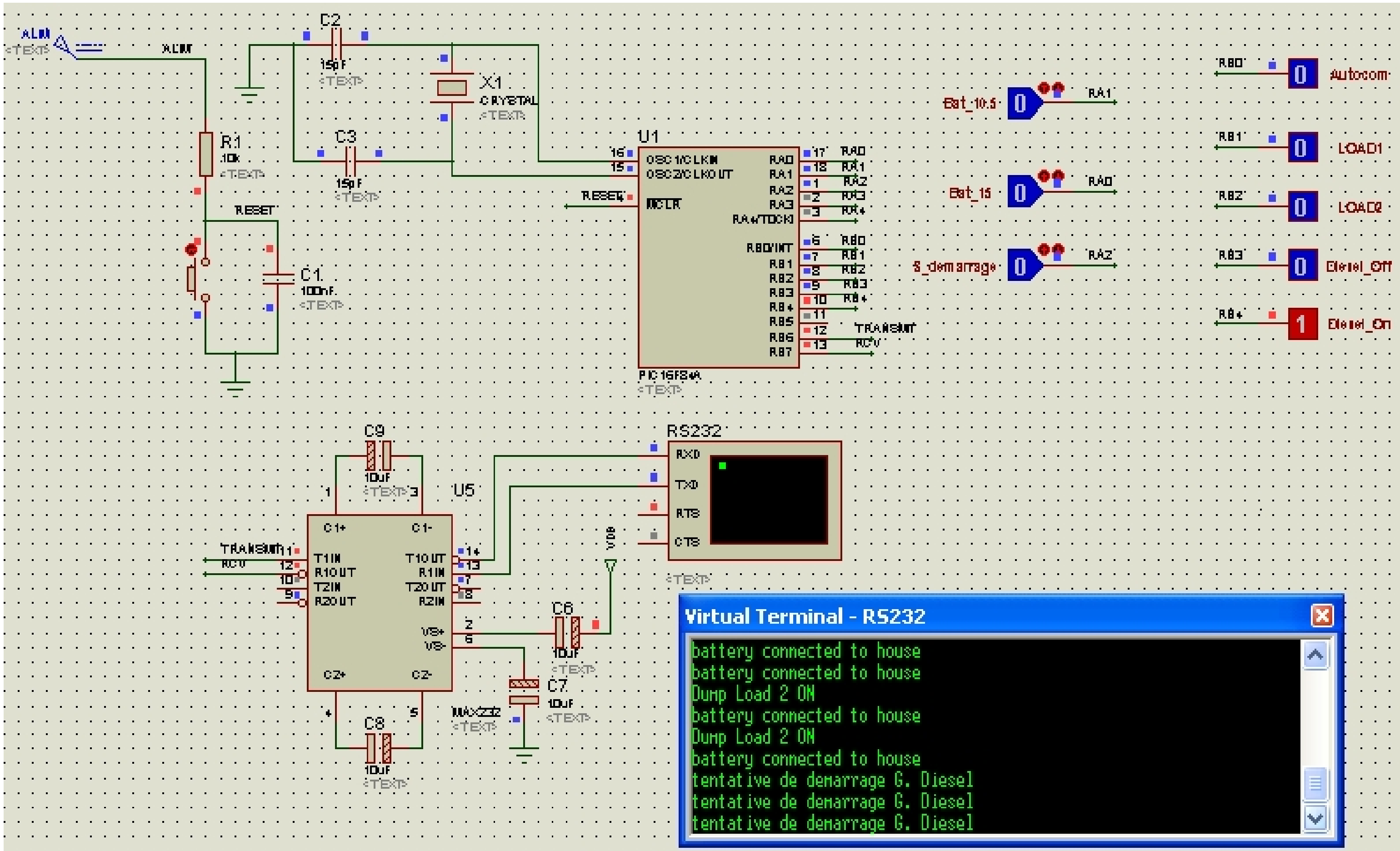

Fig. 10. Simulation the microcontroller for battery voltage Vbat < 10.5V

3.2 Case 2: Battery Voltage less than 10.5V and Generator Switched On

The output of the start-up detector switches to 1, this shows that the backup generator is effectively on operation. Then, the autocom output switches to 1, for the commutation between the battery and the backup generator in order to send energy to the utility line. This is shown on Fig. 11.

3.3 Case 3: Battery voltage greater than 10.5 V (V_{bat} > 10.5 V) and backup generator is on

The response of the module is shown on Fig. 12. In this case the diesel "Generator Off" outlet passes to the logical level 1, thereby putting off the diesel generator. Before this action, the outlet autocom passes to 0, the live line to utilities is therefore operated by the battery. The virtual terminal reads "Battery connected to house and generator switched off".

3.4 Case 4: Simulation for battery voltage greater than 10.5 Volts and generator is off

The module responses are shown on Fig. 13. The virtual terminal RS232 reads 'battery connected' to the house for smooth energy supply.

3.5 Case 5: Battery Voltage Greater than 15 Volts (V_{bat} > 15V)

As shown on Fig. 14, energy to utilities is supplied by the battery and the dump loads 1 is first connected. After a given waiting period, the dump load 2 is connected if the battery voltage is still greater than 15 V although dump load 1 has been connected.

3.6. Construction of the Electronic Module

Based on the above logical electronic diagram of our entire module, the corresponding printed circuit was erected using the, Advanced Routing and Editing Software (ARES) of Proteus professional. The printed circuit is shown on Fig 15 and the components installed are shown on Fig. 16.

After realising the various steps, diodes, resistances, integrated circuits carriers and variable resistors are implanted on the printed circuit. Next, the capacitors, transistors, voltage regulators and electric relays were implanted. Electronic module is shown in figure 17.

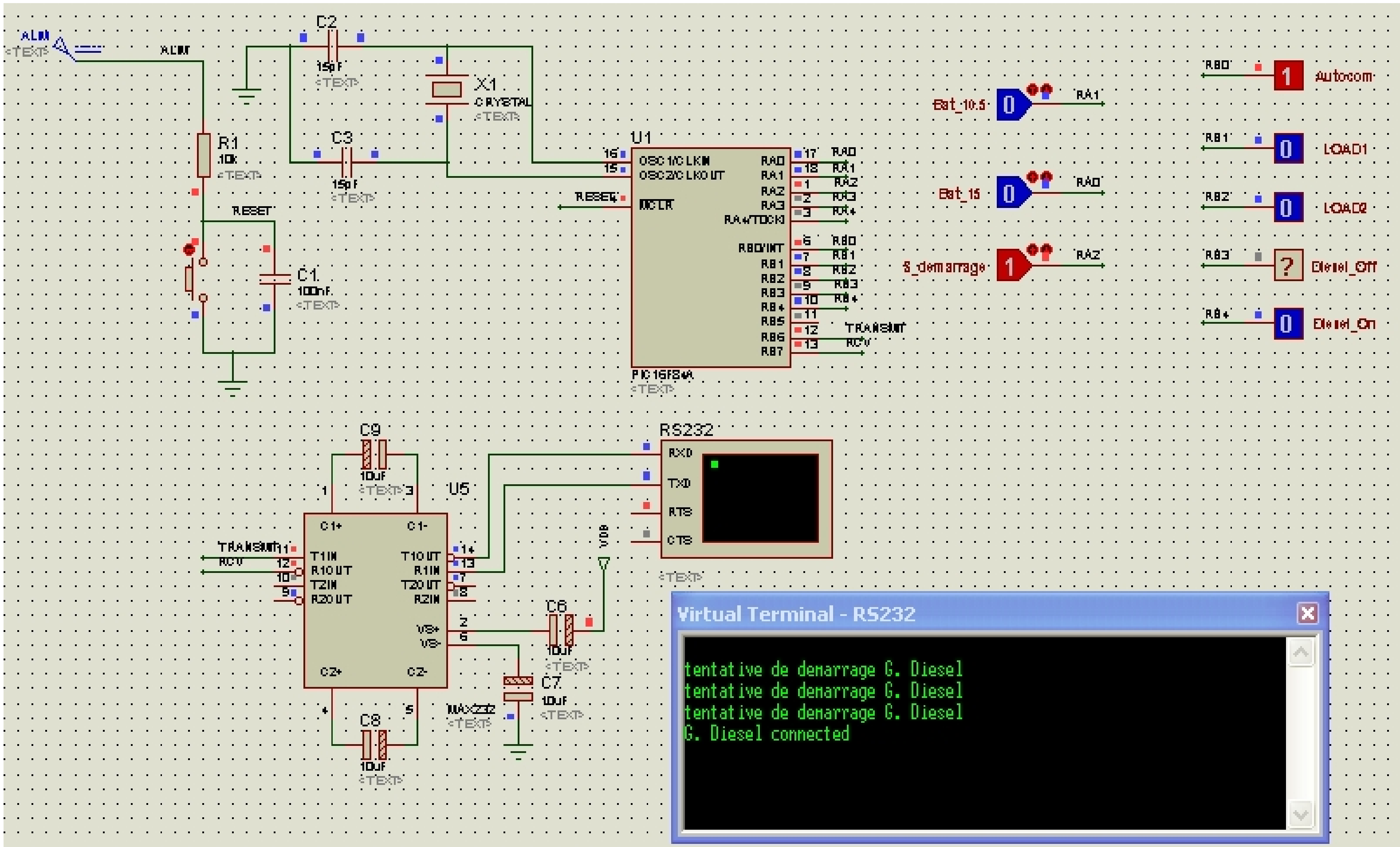

Fig. 11. Simulation of the microcontroller for battery voltage less than 10.5V and generator switched on.

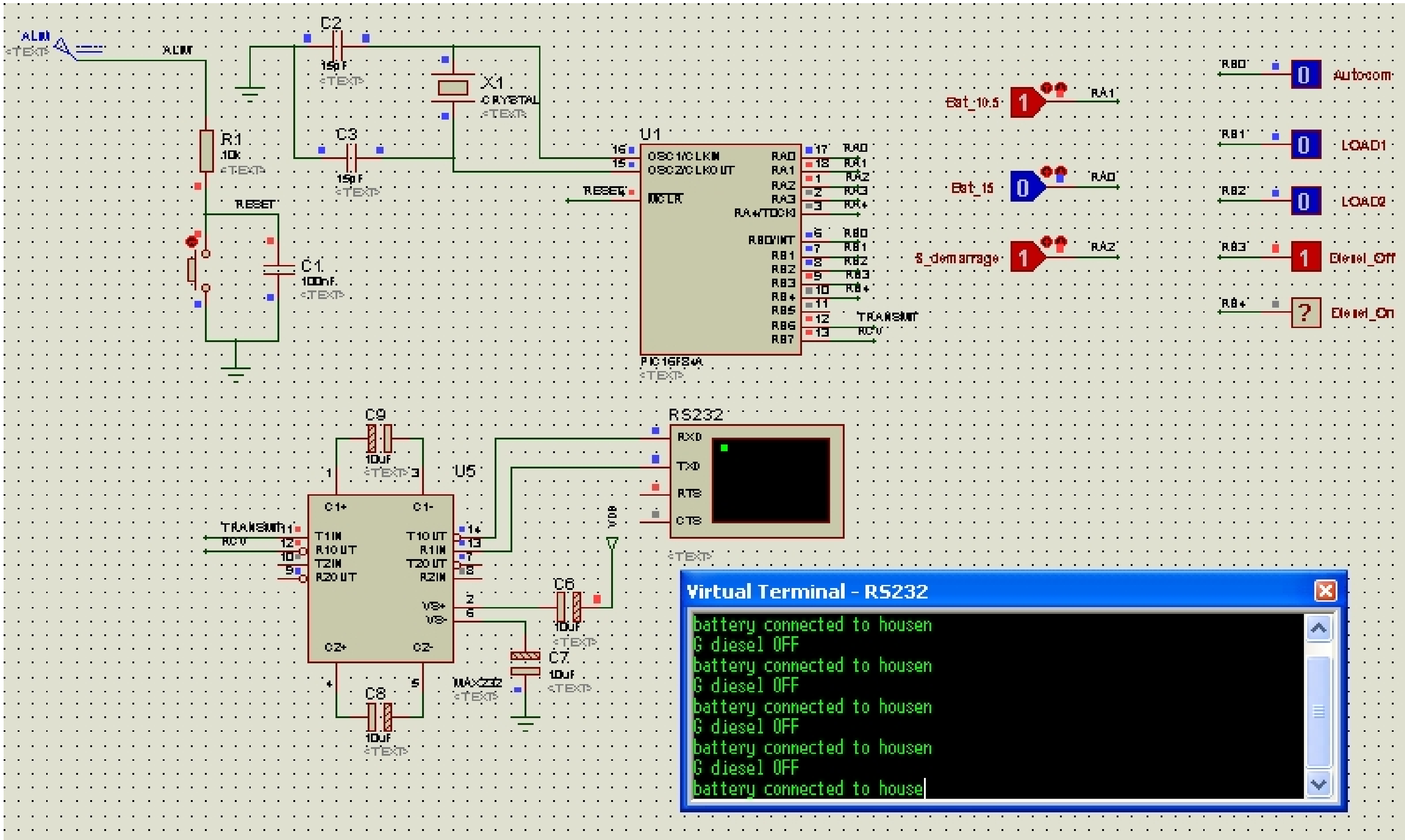

Fig. 12. Simulation of microcontroller for V_{bat} > 10.5V and diesel generator switched on

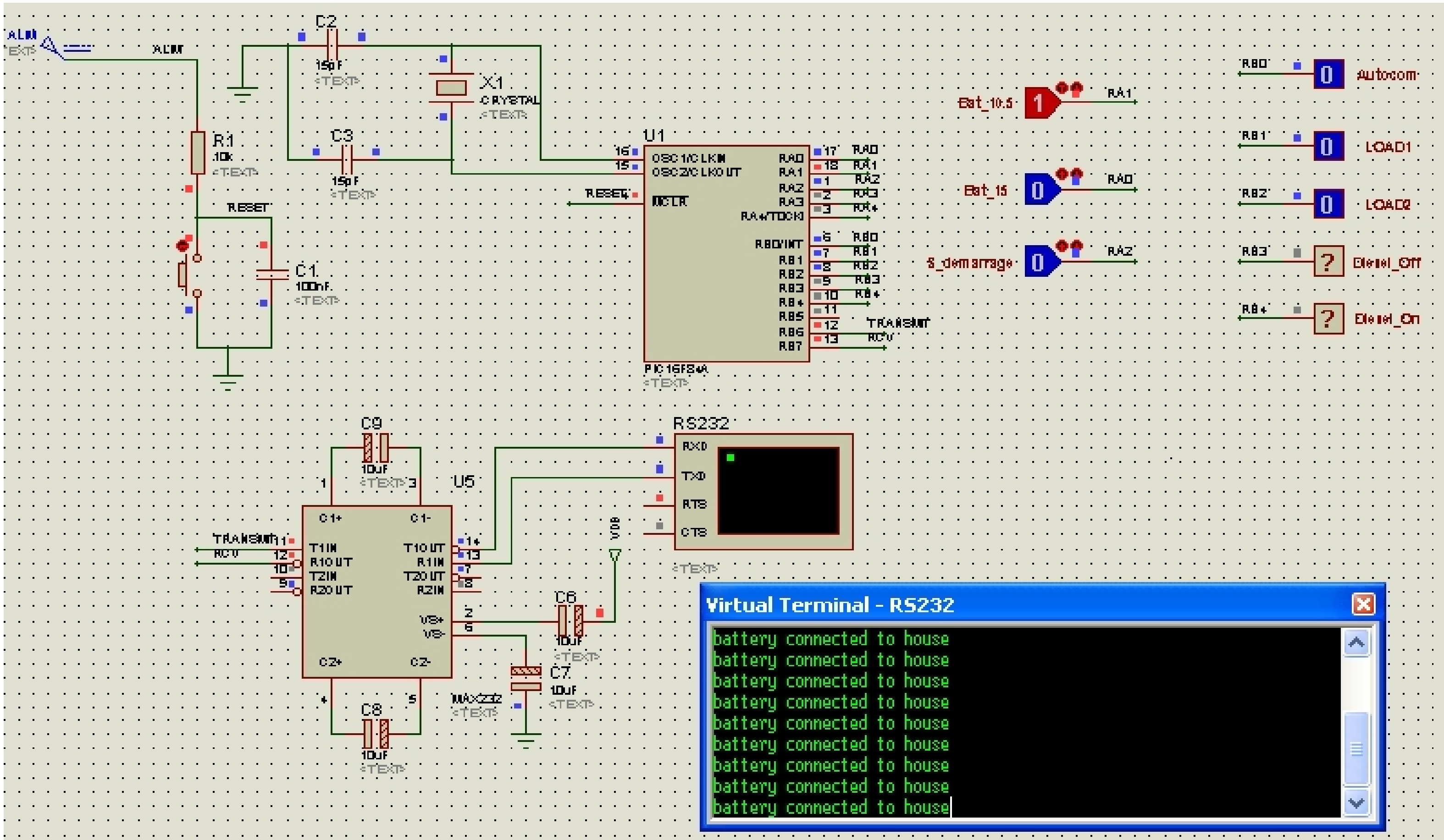

Fig. 13. Simulation for battery voltage greater than 10.5V (Vbat > 10.5V)

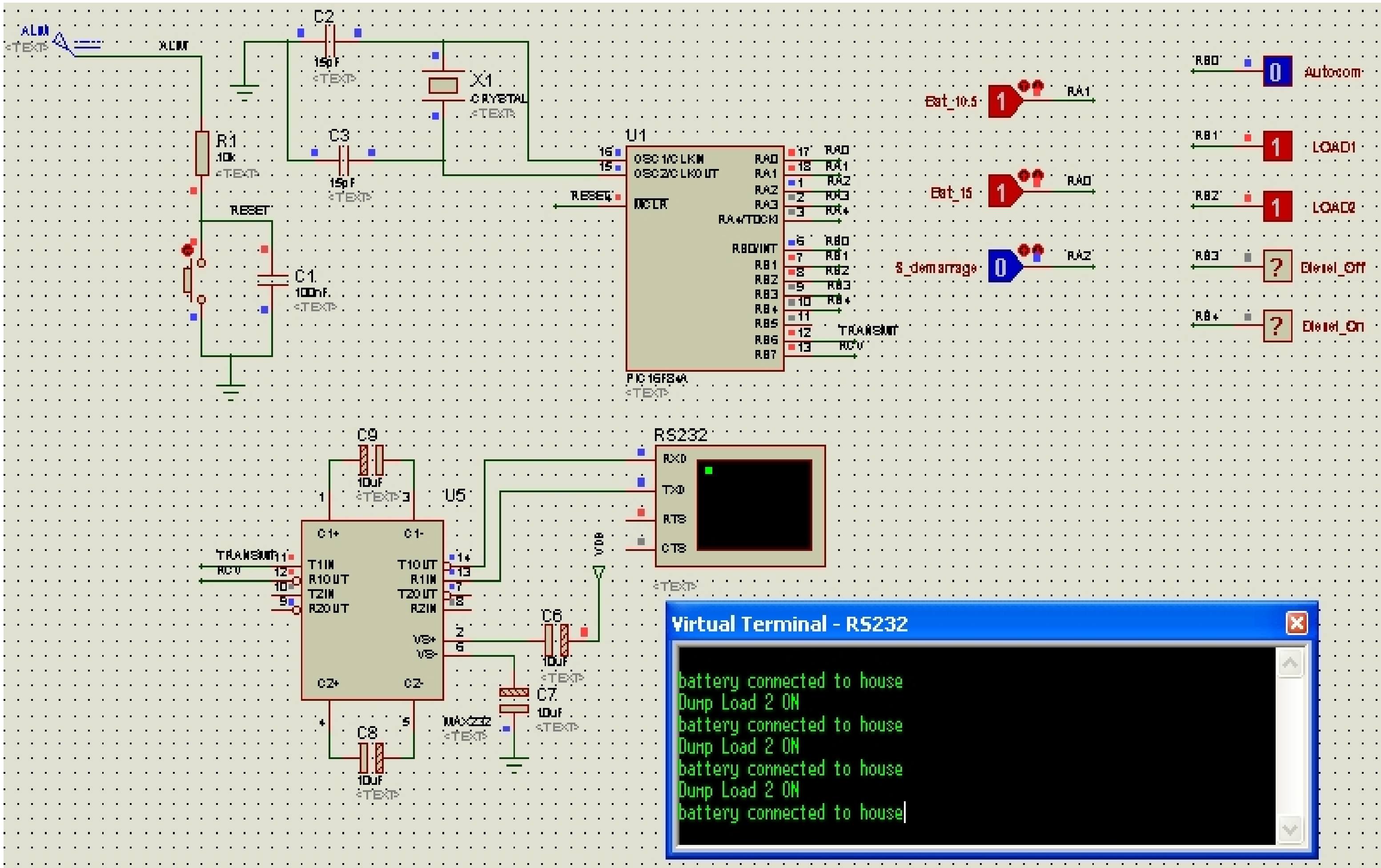

Fig. 14. Simulation of microcontroller for V_{bat} > 15V

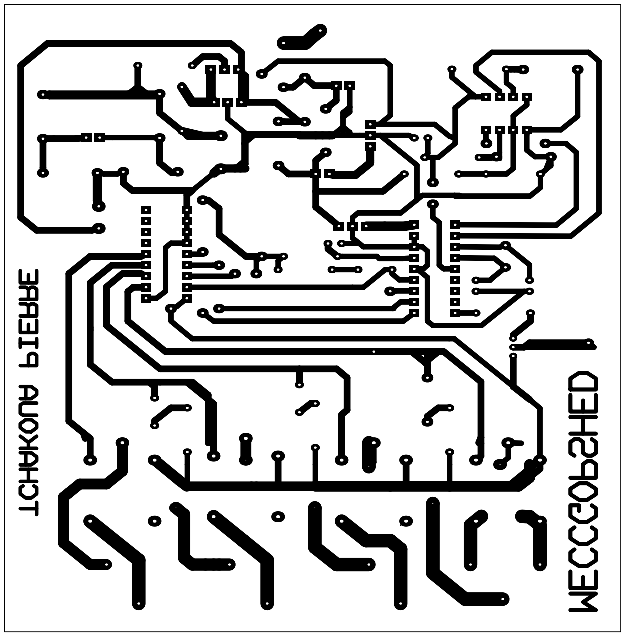

Fig. 15. Printed circuit path shown from the backside

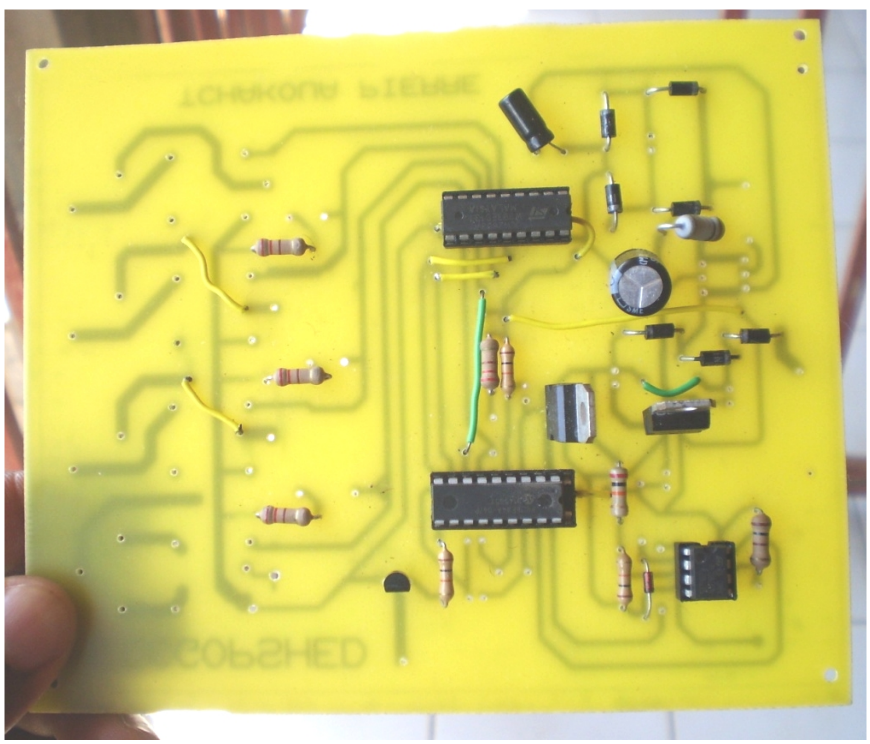

Fig. 16. Photograph showing partial implantation of the components

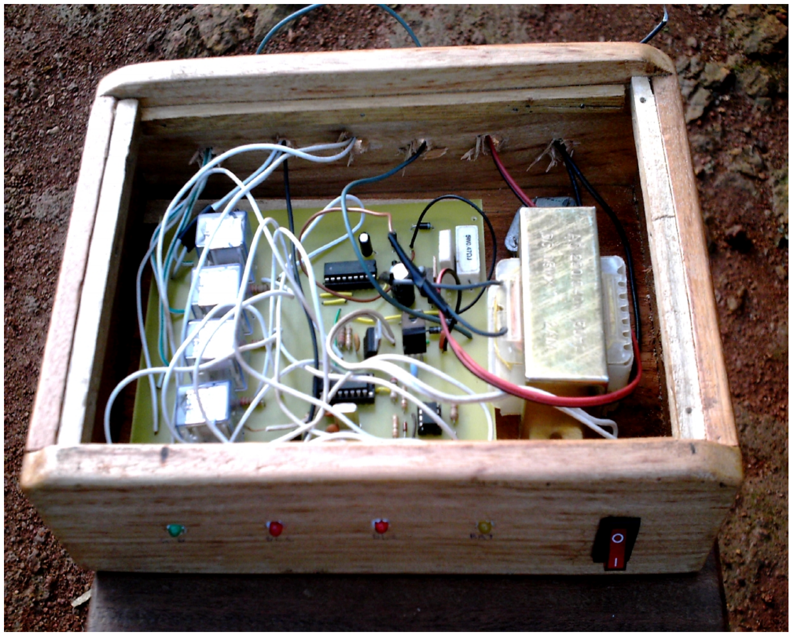

Fig. 17. Photograph showing the electronic module

3.7 FIELD Tests

Preliminary field tests were done at the University of Dschang micro wind farm using the layout in shown in Fig 2. The parameters of the micro hybrid system used are presented in Table 2.

Table 2. Parameters of the equipment used in field test

Equipment	Characteristics
Wind turbine	700 Watts, 12 Volts Hugh Piggott type with Neodymium 40, permanent Magnets and 90 turns of 1.4mm diameter wire for field windings
Solar panels	Two 100 Watts peak power solar panels connected in parallel to give out 12 volts
Dump Loads 1 and 2	1000 Watts capacity electrical resistance water heater elements
Battery Bank	Two 12 V , 120 AH Caterpillar batteries connected in parallel to give out 12 V.
Backup generator	A 5hp diesel generator connected to a bidirectional converter

The layout used in the field experimentation is shown on Fig 2 and the parameters of the various equipment used with the module are presented in Table 2. The battery bank was connected through a switch to a bidirectional converter connected to a 5hp diesel engine. Two water heater elements of 1000Watts each were used for dump loads 1 and 2. The wind turbine used in the test was a locally made 12 Volts Hugh Piggott type machine using 24 Neodymium, grade 40 permanent magnets and 90 turns of 1.4mm diameter wire for 10 field windings. The details of the experimentation and the weather data can be found in Tchakoua, 2009 and Tangka et al., 2010. Idle periods of the renewable energy facility were induced by disconnecting it from the system and at the same time inducing the module to start the generator.

Preliminary tests indicated that the module communicated successful with the different components except dump load 2 which was never turned on by the module. This could be attributed to the fact that the installation was a small one and as such dump load 1 was enough to drain energy from the system when connected. Although many of such modules are now being tested for robustness and ability to work in extremely dusty conditions, it was concluded that the module can satisfactorily manage energy produced in a small hybrid PV/diesel or wind/diesel system

4. CONCLUSIONS

An intelligent module for energy management in hybrid energy systems was designed fabricated and tested. The module is made of five blocks, mainly a power supply, a battery voltage monitor, a programmable interface controller, a battery charger, and a start up monitor block. Simulation of the system was done using the ISIS software. A protocol of activities was programmed on a computer chip that commands the activities of the module. The module succeeded in shorting off power supply to electrical loads when battery voltage fell below 10.5 V at the same time starting the generator. The module shorts off the generator when battery voltage is above 10.5V and the renewable source is producing electricity. Simulations indicated that above 15V of battery storage the module connects dump load 1 and finally connects dump load 2 if battery voltage is maintain at 15V although dump load 1 was connected. However during field tests dump load 2 was never turned on probably because dump load 1 was enough to drain energy from the system. Although field test have continued since December 2009, it can be concluded that the module can satisfactory manage energy supply in a small PV/Diesel or Wind/diesel hybrid system.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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