Vol 8. No. 2 June, 2015

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Design and Construction of A 5kva Power Inverter with Real Time Automated Power Consumption Management System

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ABSTRACT

Overcoming the obstacle of fixed power has led to the invention of DC/AC power inverters which is further strengthened by adding the automated control unit. While the position of power inverter in the market is relatively well established, there are several features that can be improved upon such as efficiency, cost, power rating and power quality performance. This paper presents the design effort to improve on power management of an inverter. The method used is to divide the system into two subsystems namely the power inverter subsystem and the control/timing subsystem. User preferences for power consumption profiles are entered using a keypad and the developed system automatically manages power consumption by turning ON or turning OFF corresponding connected loads. The system was tested and was found to have an efficiency of 89%.

Keywords: Power inverter, Real time, Power Consumption Management, .

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1. INTRODUCTION

The need for a more reliable backup power supply has become inevitable for a number of reasons. The global efforts at curbing the menace of rapidly depleting ozone layer with consequent global climatic changes had doubled efforts at utilizing renewable energy sources such as solar and wind. The use of these sources requires backup storage for effectiveness. One such backup device is the inverter- Inverters rely on backup up power stored in a battery bank to operate. Optimum utilization of this power becomes essential to be able to cut cost in terms of the number of batteries required for the battery bank and also to prolong the battery life span in terms of the depth of discharge while in use. Also optimum power utilization is necessary even when supply is from the public tariffs.

Energy management is the science involving planning, directing, controlling the supply and consumption of energy to maximize productivity and comfort and minimize the energy cost and pollution with conscious judicious and effective use of energy (Oricha and Olarinoye, 2012). One way of saving cost of energy consumption is by improving the power factor of the power supplied to electrical appliances (Akram and Ijaz, 2013). This is necessary, because in developing countries, energy crises exist because of old distribution system and since the loads are more inductive, they become the source of reverse power flow thereby producing significant amount of resistance to the incoming power and create excess amount of heat and power loss within the transmission lines (Akram and Ijaz, 2013). Another method uses the idea of “energy on demands” meaning that energy is provided only when needed. It adopts a predictive artificial neural network to forecast energy demand (Pizzutu et. al). It is important to understand that energy user behavior is about the most important factor in achieving energy consumption efficiency (Kirsten, 2013). The methods already discussed do not address this factor (user-behavior) of energy consumption efficiency. Home power management system designed in this work employs the method of maximizing the efficiency of the supply to electrical appliances/devices, by controlling their energy usage. It takes over the user-behavior side of energy consumption efficiency and ensures that energy is supplied to appliances only when needed as decided by the energy user according to user-timing parameters supplied to the system.

2. METHODOLOGY

The intelligent management system is divided into two subsystems. Each subsystem is designed to accomplish a unique goal. The first subsystem is the control and timing unit which allow input timing parameters for it to support timing functions. The second subsystem is the power inverter, which performs the actual inversion from the input renewable power sources to the output for load supply.

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Power Supply Unit. The power supply circuit provides power for both the battery charging circuit which powers the inverter and the control unit. Power supply requirements for the inverter is 24V DC and main supply unit which supply 220V to 240V AC which operate on automatic switch-over whenever there is an input from the main supply system.

Voltage Regulator Section. In Fig. 1 LM7812 and LM7805 are used to provide a 12V and 5V DC Voltage to the different sections of the circuit.

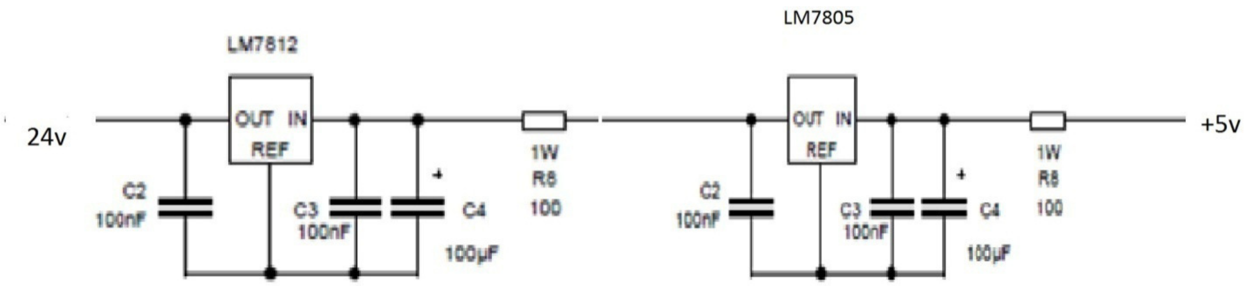

Fig. 1: Regulators Connections

Microcontroller. The PIC18F4520 microcontroller chip is powered with 5 volts through a LM7805 voltage regulator; it supplies power at constant 5V at a required current of 0.5mA
Output voltage =5V .

Therefore,

$$R_1 = \frac{5V}{0.5mA} = 10k\Omega.$$

This serves as the limiting resistance. Resistance value of 10kΩ was chosen for R_{36}, R_{37}, R_{38}, and $R_{39,}$ R_{40} which servers as pull-up resistors. The keypad which includes numeric and control keys are connected to dual purpose Input/output ports (RCO) for the Rows i.e. pins 23-24 configured as output. Columns are connected to RCO pins, (pin 15-18) configured as input with interrupts. In this configuration, three pull-up resistors were added in order to apply a high level on the corresponding input pins. Pin 13 and 14 of the microcontroller are for oscillation. A crystal oscillator of 4MHz was used. A crystal oscillator of 4MHz was used because of its stability and availability. $C_1 = C_2 = 22pf$ for PIC. Pin 18 and 23 is connected to ULN2803 IC (U1) which interfaces the control circuit with the relays.

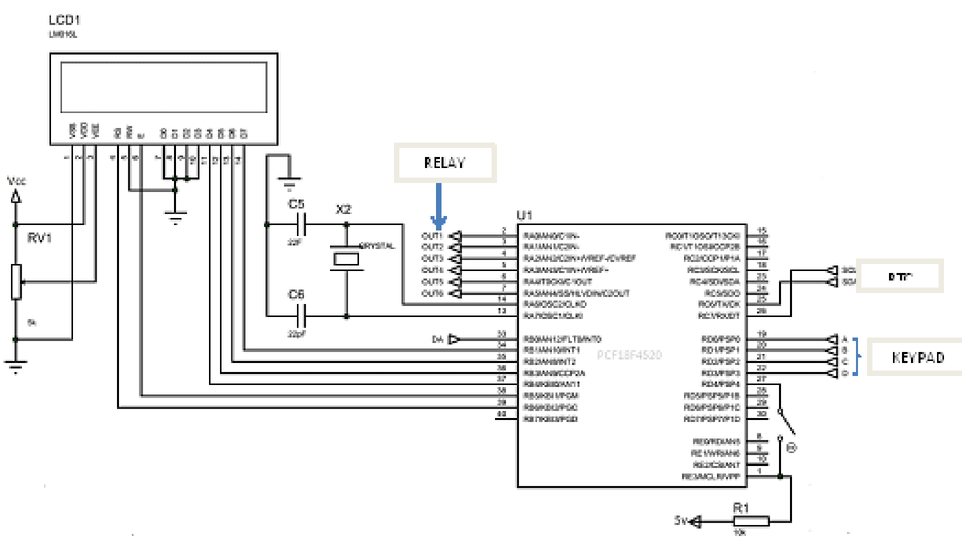

Fig. 2: Microcontroller IC

Vol 8. No. 2 June, 2015
African Journal of Computing & ICT

www.ajocict.net

The LCD is the output display of the system; it is driven by the microcontroller using ASCII information of the received byte. I/O pins 34 to 39 connect to data pins D4 to D7 of the display as shown in Fig. 2. RV_2 is for brightness intensity control and a chosen value of 10k was used.The flowchart for the control algorithm is given in Fig. 3.

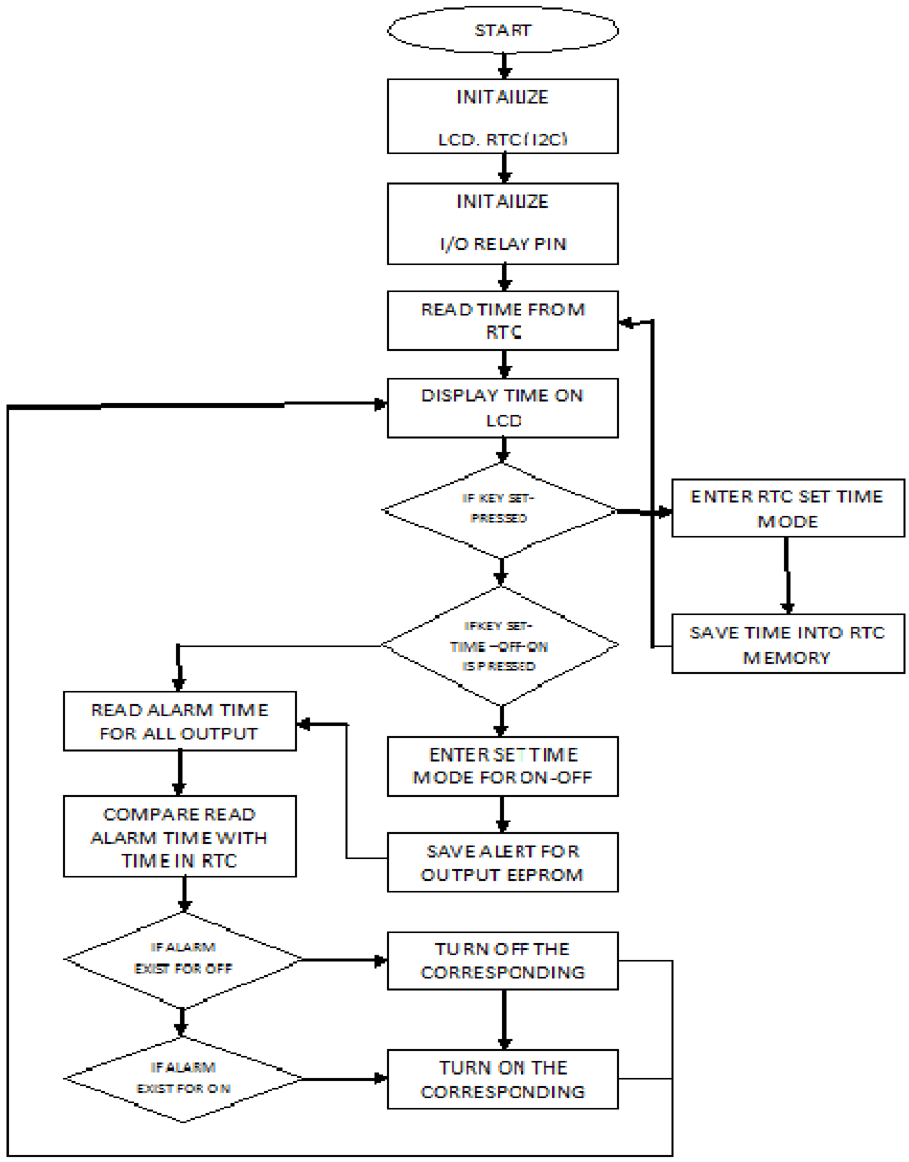

Fig. 3: Control Flowchart

Real-Time Clock. A timer is a series of divide-by-two flip-flops that receive an input signal as a clocking source. The binary value in the timer flip-flops can be thought of as a "count" of the number of clock pulses since the timer was started. It initiates return of the control to the operating system after the set system clock periods. A 32.768 kHz quartz crystal has to be connected to OSCI and OSCO. A trimmer capacitor between OSCI and VDD (R2 AND R3) is used for tuning the oscillator, Fig. 4.
R2 and R3:

pull-up resistor = $\frac{tr}{Cb}$……………. (2.2)

where t_r is 1µS and C_b is pF.

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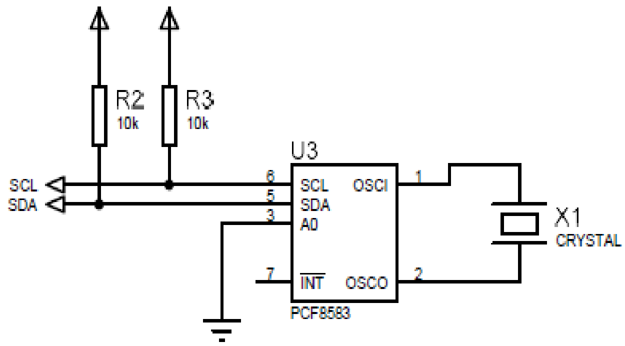

Fig. 4: Real time clocks

The Keypad. The MM74C922N is a 16-key encoder that includes all the internals to take the output of a 16-key switch and encode it onto only four outputs using a truth table.

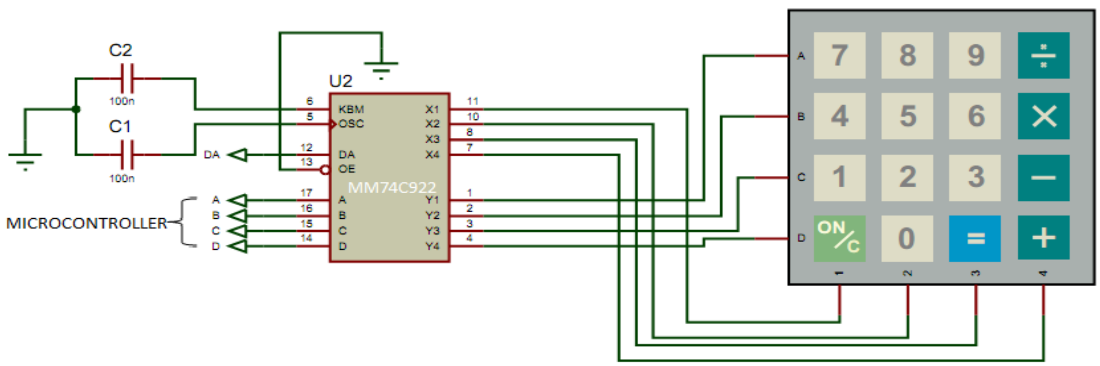

Fig. 5: Keypad Encoded to Interface

The MM74C922 can be used an external clock for synchronous keypad scanning, has internal pull-ups, and has an internal debounce circuit, both the scan rate and debounce time is configurable via an external clock or capacitor. It also keeps the last key pressed on the outputs even after the key has been depressed, in case the MCU has a moment and needs to retrieve the value again (at least before the next key is pressed). It also operates from 3V to 15V so it integrates well into TTL and CMOS designs. The rows of the keypad are connected through its internal pull-up resistors when no key has been pressed. When a key is pressed the chip goes through its debounce mechanism and when that times out, the encoded data is latched and the DA pin (Data Available) goes high. The DA pin stays high (logical 1) until the key is released, and then it drops to a logical 0. There is also an OE pin (Output Enabled) which is the inverse of the DA pin. **MOS Driver**. The 50Hz alternating signals from the oscillator stage are used to drive the MOSFET. The signals are however applied to a complementary push and pull BJT circuit acting as the MOS driver circuit. The circuit configuration of the MOS driver is shown in Fig. 6. R1 = R2 = R3 = R4 = 560Ω was chosen

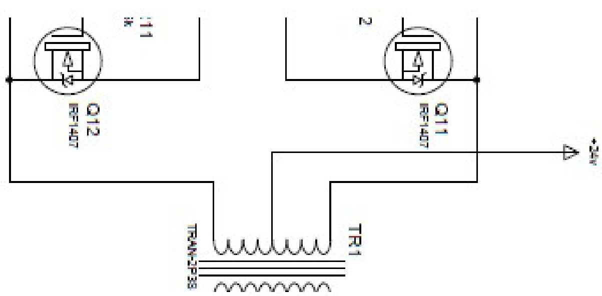

Fig. 6: MOS Driver

Vol 8. No. 2 June, 2015
African Journal of Computing & ICT

www.ajocict.net

The MOSFET stage conducts the necessary load current through the step up transformer. The MOSFET used in the design is the *IRFP260* N-channel E-MOSFET. The circuit arrangement of the MOSFETs is shown in Fig. 7.

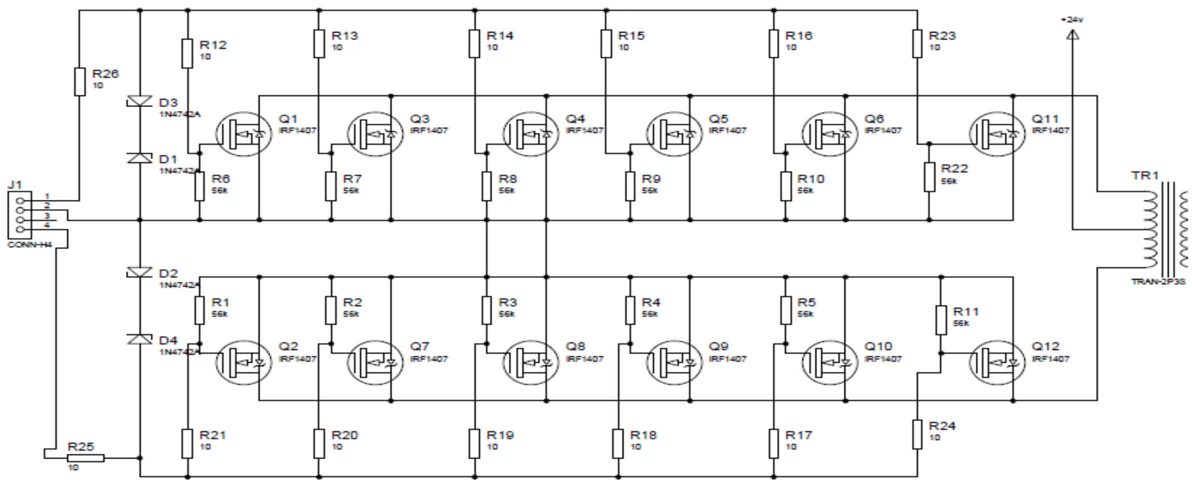

Fig. 7: Arrangement of the MOSFET

The value for resistors R11, R14, R16, R18, R20, R22, R24, R26, R28, R30, R32, and R34 are all 100Ω. On the other hand, the values for resistors R12, R13, R15, R17, R19, R21, R23, R25, R27, R29, R31, R33 are all 230Ω.
The transformer power rating is 5KVA, and primary voltage is 24V. Therefore, the full load primary current I_p is given by:

Primary Current, $I_p = \frac{KVA\ rating}{Input\ voltage}$ …(2.3)

Therefore $I_p = \frac{5000}{24} = 208.3A$

The D I_D (continuous) at TC = 25°C is 33A which is the maximum current.

Taking the average $\frac{33}{2} = 16.5A$

Number of MOSFETS,

$nM = \frac{Primary\ current}{Drain\ current}$ ….. (2.4)

Therefore number of MOSFETs required is: $= \frac{208}{16.5} \approx 12.6$ mosfets,
that is, a total of 12 MOSFETs, taking an even number of 12 to have six on each halve, will be enough to provide the full load current. The Total Dissipation at TC = 25°C 180W, the derating factor is 1.44w/°c the Drain Current I_D (continuous) at TC = 100°C is 20A (*IRFP260*N data sheet). In order to avoid the negative effect of these factors which can disrupt the operation of the system, the MOSFETS were installed on a heavy aluminum heat sink to take care of heat dissipations.

Transformer Design. Working with an ideal transformer, where the output is equal to the input power,

$\frac{Vs}{Vp} = \frac{Ns}{Np}$……………………………… (2.5)

$V_S I_S = V_P I_P$…………………………(2.6)

African Journal of Computing & ICT

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Where V_p=primary voltage, I_p=primary current, N_p=number of turns in primary coil, V_s=induced voltage in primary coil, I_s=secondary current, N_s=number of turns in secondary coil, and with a battery peak voltage of 24V, the output expected from the inverter is

$V_{rms}=\frac{Vp}{\sqrt{2}}$………………...…………(2.7)
$V_{rms}=\frac{24}{\sqrt{2}}=17V_{rms}$

From equation 3.6; secondary current = $\frac{\text{secondary power}}{\text{secondary voltage}}=\frac{5000}{220}=22.72A$

Assuming a transformer efficiency of 96%,

The required current will be:

$I_{eff}=\frac{22.72}{0.96}=23.66A\cong 24A$

From equation 3.6 Transformer primary current;

$I_p=\frac{220x22.72}{24}=208.3A$

Effective primary current =208.3x0.96=199.97A

The diameter of the core used for the primary windings is 22guage while that of the secondary is 15 gauge but;
$V_T=k\sqrt{s}$……...........………………(2.8)

Where V_T = e.m.f per turn and S=kvA, k is the specific magnetic loading of the transformer. it varies from 0.50 to 0.75 for a single phase core. Assuming k is $0.55\sqrt{s}$ and s=5kvA

$V_T=0.55\sqrt{5}=1.23$v/turn

Number of Turn: The number of turns is obtained according to

$V_T=\frac{V}{N}$ …………………………….. (2.9)

For the primary side, $N_1=\frac{V1}{Vt}=\frac{24}{1.23}\cong 20$ turns.

For the secondary side, $N_1=\frac{V2}{Vt}\cong 179$ turns. Since the winding is centre-tapped on the primary side for both halves of the switching period, the total primary winding will be $N_1=2\times 20=40$ turns

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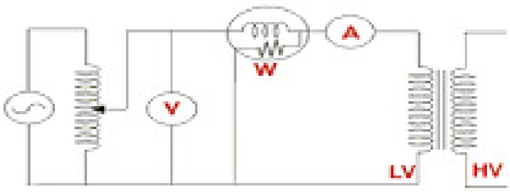
3. TEST, RESULTS AND DISCUSSIONS

The complete circuit diagram is shown in Fig. 8. Testing was carried out and test results of the system discussed. Fig. 9 shows the complete device.

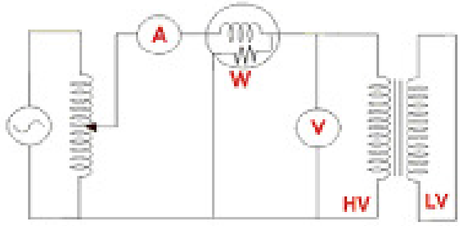
Fig. 9: Picture of Inverter with power consumption management.

Open and short circuit test. For the open circuit test, the secondary was kept open circuited and nominal value of the input voltage was applied to the primary winding and the input current and power were measured. Fig. 11 illustrates the setup. The no load current at rated voltage is less than 1 percent of nominal current and hence the loss and drop that take place in primary impedance due to the no load current I_0 is negligible.

The purpose of the short circuit test is to determine the series branch parameters of the equivalent circuit. In this test, primary applied voltage, the current and power input are measured keeping the secondary terminals short circuited. Let these values be Vsc, Isc and Wsc respectively. Table 1 gives the test results for both open and short circuit tests and is used to plot Fig.s 12 and 13 for open and short circuit readings respectively.



(a)



(b)

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Fig. 10: (a) Open Circuit test (b) Short circuit test

African Journal of Computing & ICT

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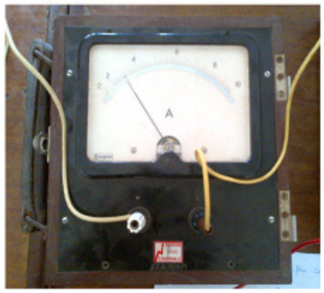

Figure 11a: Ammeter reading

Figure 11b: Wattmeter reading

Figure 11c: Voltmeter reading

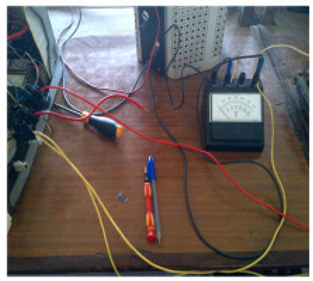

Figure 11d: HV side open circuited

Fig. 11: Open circuit readings

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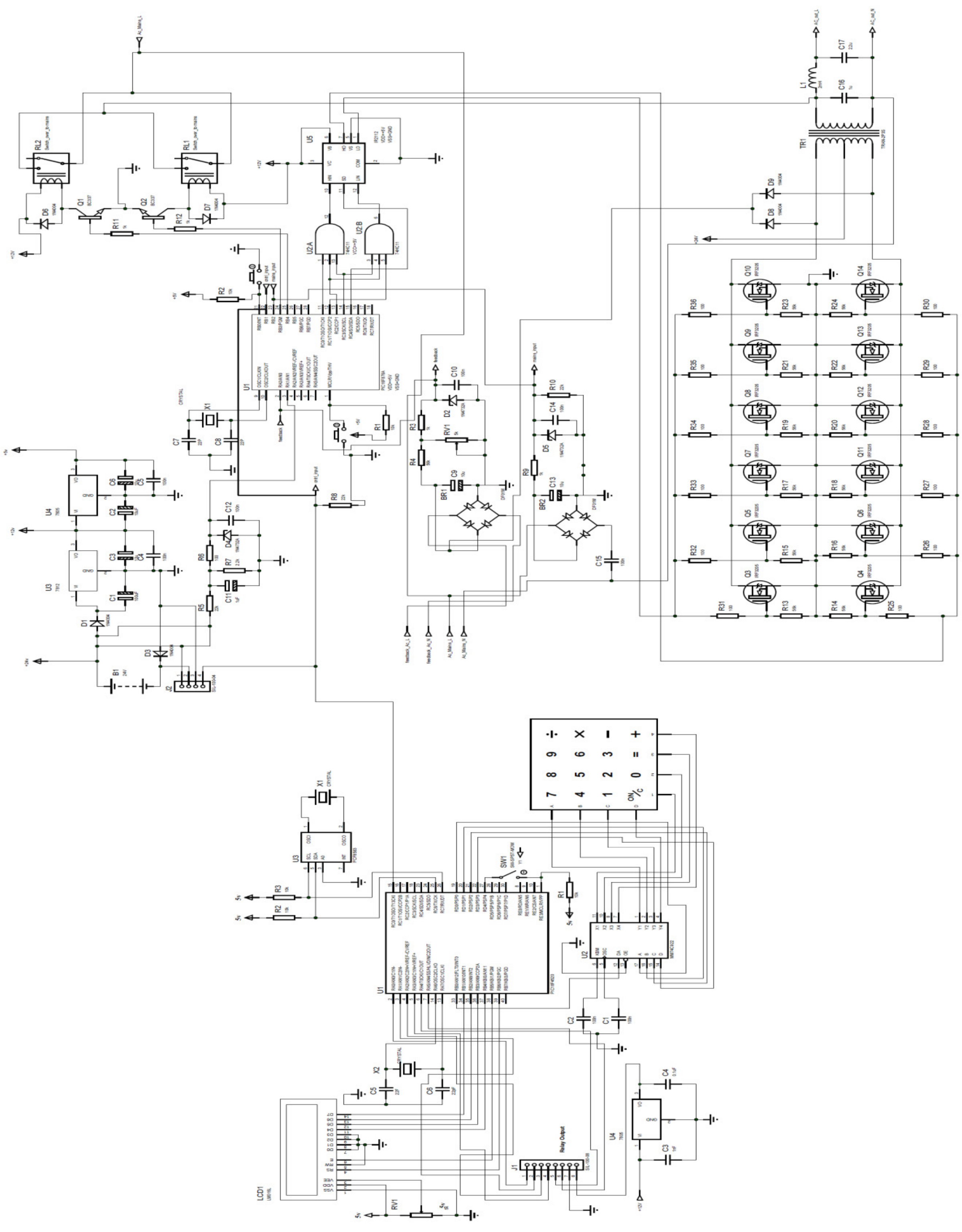

Fig. 8: The complete Circuit diagram

Vol 8. No. 2 June, 2015
African Journal of Computing & ICT

www.ajocict.net

Table 1: Open load test values

OPEN CIRCUIT TEST			SHORT CIRCUIT TEST		
VOLTMETER(V)	WATTMETER(W)	AMMETER(I)	VOLTMETER(V)	WATTMETER(W)	AMMETER(I)
20	25	0.1	0	0	0
40	42	0.3	9	49	5
60	66	0.7	20	95	10
80	84	1.3	30	143	15

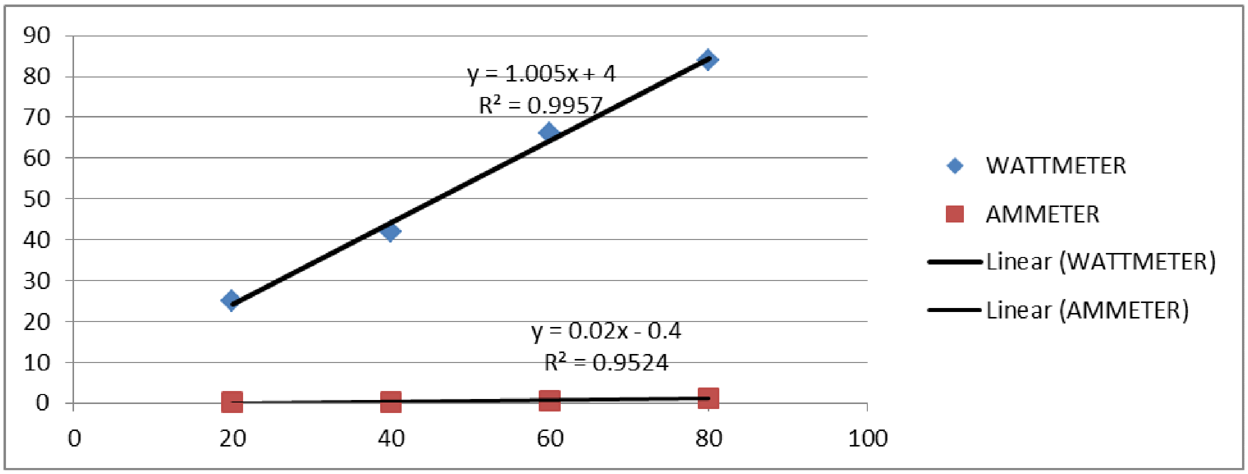

Fig. 12: A plot for the Open circuit test

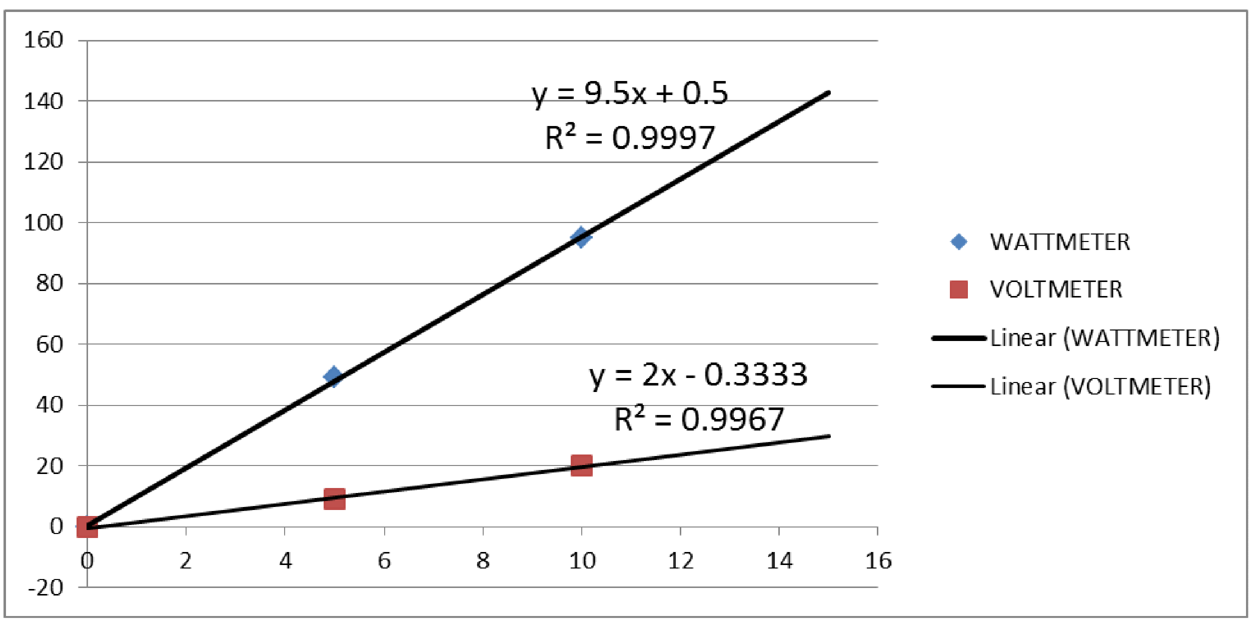

Fig. 13: A plot for the Short circuit test

Vol 8. No. 2 June, 2015

African Journal of Computing & ICT

www.ajocict.net

The data in Table 1 is used to plot graphs to extrapolate values for the rated current of 15Amp due to the limitation in the calibration of the test tool.The modeled equations to extrapolate values for the required Volt and Watt are given in the graphs.

Timing test. The connection points of loads to the designed inverter system are referred to as ports in the remaining sections of this paper. The On and Off times for Port 1 through Port 4 were set and the device was allowed to operate to determine when the indicator bulb came and went off indicating the ON and OFF times. Port 5 which is unregulated was manually switched ON and OFF. Fig. 16 gives the output ports timing control test. Table 3 gives the results for output ports timing control. Table 2 gives the tests results for the output timing control

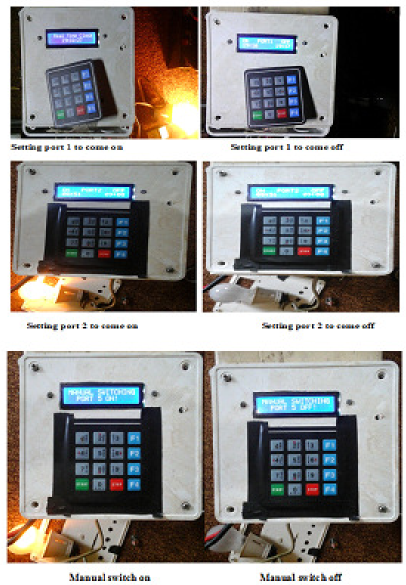

Fig. 14: Output Ports timing control test.

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TABLE 2: Output ports Timing Control

PORT	MODE	PORT SETTINGS		OPERATIONAL STATUS		OBSERVATION
		ON	OFF	ON	OFF	
1	Regulated	19:16	19:17	✓	✓	The light bulb came on and off accurately at the set time.
2	Regulated	08:15	09:08	✓	✓	The light bulb came on and off accurately at the set time.
3	Regulated	08:56	09:56	✓	✓	The light bulb came on and off accurately at the set time.
4	Regulated	08:54	08:55	✓	✓	The light bulb came on and off accurately at the set time.
5	Unregulated	ON	OFF	✓	✓	The light bulb came on and off accurately at the set time.
6	unregulated	ON	OFF	✓	✓	The light bulb came on and off accurately at the set time.

Table 2 confirms that the system exhibited satisfactory automatically control of the output ports for ac load supply.

Vol 8. No. 2 June, 2015
African Journal of Computing & ICT

www.ajocict.net

4.0 DISCUSSION

From the test data in Table 1 and 2, a rated voltage of 80 Volt from the open circuit test was used to obtain a value of 84 Watts and 6.2Amp when no load is applied, at rated current of 15Amp while from the short circuit test a value of 30 Volt and 143 Watts was obtained.

The % loading mean is obtained from equation 10 *(Mohan, 2012)* and the maximum load in KVA is obtained from Equation 11: *(Theraja, 2008)*

% Loading mean,

$$x = \frac{KVA\ x power\ factor}{KVA\ x power\ factor + total\ losses} \ldots\ldots (10)$$

Efficiency,

$$\eta = \frac{x \times S \cos\theta}{x \times S \cos\theta + Pcore + x2 Pcu} \ldots\ldots\ldots .(11)$$

The designed Full Load kVA rating, S = 5kVA. Core loss at rated voltage & frequency, P_{core} = 84watt. Full load copper loss, P_{cu}= 143watt. For Load power factor, cos Θ = $\frac{143}{30 \times 15} = 0.32$.

% loading means,

$$x = \frac{5000 \times 0.32}{5000 \times 0.32 + (143 + 84)} = 0.88$$

Efficiency,

$$\eta = \frac{0.88 \times 5000 \times 0.32}{0.88 \times 5000 \times 0.32 + 84 + 0.88^2 \times 143}$$

% efficiency, η = 89%

Per unit value of loading for η_{max} is $x = \sqrt{Pcore/Pcu}$

$$= \sqrt{84/143}$$

$$x = 0.76$$

Thus the load for $\eta_{max} = x \times S$ = 0.76 X 5kVA

The achieved load for η_{max}(maximum efficiency) = 3.8kVA

The maximum load the inverter can carry is 3.83kVA, although it was designed to be able to carry a load of 5kVA. The variation in power rating was due to energy losses in the transformer. Although transformers are very efficient devices, small energy losses do occur in them due to the resistance of windings, Flux Leakage, Eddy Currents and Hysteresis loss.

Tests were carried out on all the ports namely the four regulated and two unregulated ports. For the regulated ports, ports one to four, ON times and OFF times were inputted into the real time clock. The ports acted in accordance with the set times this was confirmed with the electric light bulb. When a regulated port came ON, the light bulb connected to it came ON and when the regulated port was programmed to go OFF, the light bulb also went OFF. In the case of the two unregulated ports, the ports had to be switched ON and OFF manually. Each time an unregulated port was switched ON, the electric light bulb connected to it came ON and when the port was switched OFF the electric bulb connected to the port went OFF.

4. CONCLUSION

We have presented the design efforts of a 5kVA inverter with real time automated power consumption management system. The developed inverter system was tested extensively and was found to provide a higher quality of output power with an efficiency of 89%. The implication of this work is less damage to sensitive equipment and using power on a need-to-use basis..

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