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ANALYSIS AND IMPLEMENTATION OF ELECTRICITY GENERATION OF 1000VA USING WIND TURBINE

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ABSTRACT

The project involved the design and construction of a three-blade wind turbine, selection of generator by consideration of the available wind speed and the maximum generated voltage per revolution, and assembly of the pulse width modulated inverter with microontroller based status display and low battery shutdown system. On completion of the work, tests were conducted and the result shows that the design work was very good, the output of the generator was good enough to charge the batteries and the inverter performed an excellent task of converting the direct current (DC) voltage available in the battery to alternating current (AC) at 230V 50Hz 20". Furthermore, results from the discharge characteristics of the battery shows that as the battery is being used up, the output voltage remains constant.

Keywords: *wind, blade, turbine, magnetic field, battery, oscillator, inverter, controller*

1. INTRODUCTION

The wind power generating plant is a system which consists of a wind turbine, a direct current (DC) generator or alternator, a battery bank, and an inverter. Wind is the movement of air across the surface of the Earth, from areas of high pressure to areas of low pressure. The surface of the Earth is heated unevenly by the sun depending on factors such as the angle of incidence of the sun rays at the surface (which differs with latitude and time of day), and whether the land is open or covered with vegetation. Also, large bodies of water, such as the ocean, heat up and cool down slower than the land. The heat energy absorbed at the Earth's surface is transferred to the air directly above it, and as warmer air is less dense than cooler air, it rises above the cool air to form areas of high pressure and thus creates a pressure differential. The rotation of the Earth drags the atmosphere around with it causing turbulence. These effects combine to cause a constantly varying pattern of wind across the surface of the Earth [1- 5]. Wind power has been extensively studied in [6- 8], and it is defined as the conversion of wind energy into a useful form of energy, such as in: wind turbines to generate electricity, windmills for mechanical power, wind pumps for water pumping or drainage, or sails to propel ships [9-12]. Wind power has grown steadily over the last decade at an average of 30% per year [13]. A total of 120 GW is produced annually from wind power. The largest wind turbine is the Emerson, located in Texas USA with an output of 6MW. The largest wind farm is also in Texas with a capacity of 420 turbines and produces a total of 735 MW of energy [14]. With such energy production from wind, over 160 million tonnes of carbon dioxide are cut, hence, reduced emission of greenhouse gases [14].

According to the European wind energy association (EWEA), 12% of the power demand of the whole world will be provided by wind generation in 2020 [15]. At present, the total installation capacity of

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wind power generators has reached 31128 MW and the generation cost per kilowatt-hour has been reduced from 38 cents in 1982 to 4 cents in 2001 [15].

In general, wind power generators can be installed by grid connection with the electrical network. For the offshore islands or remote area which cannot be reached by bulk power system networks, the wind power generators can be operated standalone or integrated with diesel generators and photovoltaic (PV) panels to serve the power demand [16].

Wind turbines serve as a means to transform the kinetic energy of wind into power. This process begins when wind contacts the turbine blades and transfers some of its kinetic energy to them, forcing them to rotate. Since the blades are connected to the main shaft through the rotor, the shaft rotates as well, creating mechanical energy. The main shaft is usually connected to a gear box which rotates a parallel shaft at about 30 times the rate of the main shaft. At high enough wind speeds, this amplification creates sufficient rotational speeds for the generator electrical output [17].

A large wind farm may consist of several hundreds of individual wind turbines which are connected to the electric power transmission network. Offshore wind farms can harness more frequent and powerful wind than are available to land-based installations and have less visual impact on the landscape but construction costs are considerably higher. Small onshore wind facilities are used to provide electricity to isolated locations, and utility companies increasingly buy back surplus electricity produced by small domestic wind turbines [5]. In contrast to existing works, this study aims to analyze the implementation of electricity generation of 1000 VA using wind turbine. In particular, this study involves the novel design and construction of a three-blade wind turbine, selection of generator by consideration of the available wind speed and the maximum generated voltage per revolution, and assembly of the pulse width modulated inverter with microcontroller based status display and low battery shutdown system.

2. DESIGN ANALYSIS

The design considerations for the various units that make up the wind power generating system consist of three sections listed as follows:

- ➢ The turbine
- ➢ The inverter and,
- ➢ The battery bank

2.1 The turbine

The turbine design involves the following steps:

1. Selection of generator
2. Construction of the blades
3. Assembly

2.1.1 Selection of generator

The key to selecting a very suitable generator is to find a motor delivering a voltage high enough to charge batteries at the typical speed of the wind turbine and a rating close to the power expected to be produced. Residential wind turbines typically rotate at about 150 to 250 revolutions per minute (RPM) with a strong, steady wind. They will usually charge batteries, and with some losses, must produce at least 15 volts DC to charge a 12 V battery [5]. The DC motor must generate at least 1V for each 10 RPM to get 15V at 150 RPM. Divide the rated motor voltage by the rated speed to get approximate volts/rpm. If the motor is rated 240V at 1200 RPM, it will generate 0.2 volts per RPM or 20V for 100 RPM, which is excellent. Motors that generate less voltage are less expensive and can still be used but will require gears or pulleys to drive them at higher speeds. Such arrangements reduce the efficiency of the wind turbine installation.

Based on this assumption, availability and calculations, we choose a motor 300 RPM and 28V output so that at 150 RPM, it will generate 14V.

2.1.2 Construction of the Blades

Wind turbine design is the process of defining the form and specification of a wind turbine in order to extract energy from the wind. Designing the blades is a detailed process that requires precision and accurate measurements. One of the main considerations in the choice of materials and manufacturing technology is the length of the blade. As the blade length increases, the weight is also expected to increase. This is not sustainable for a number of reasons (transport limitations, load on the bearings, load in the blade structure, and load in the tower etc.,) in an attempt to reduce weight and to attain accurate precision required in the application, designing and manufacturing with light steel provides some considerable challenge.

2.1.2.1 Listed below are steps and processes followed when designing these blades.

1., Measure out the blade length on the construction paper so that each blade is 60.96 centimeters. The construction paper will serve as a model for cutting the blades out of the steel pan. When selecting the steel blade, ensure that the blade has 7 centimeters' thickness in proportion to its length.

2., Cut the construction paper into quarters, lengthwise. Ideally, a size model should be made when designing the blades so that the production process is made easier by having a template. The construction paper is the same length as the steel cut span, and wide enough that it is gummed around the steel pan section accurately.

3., Mark a horizontal rectangle on the bottom edge of each blade template, starting at one side. Cut out the rectangle, the purpose of the rectangle cut-out is to provide an attachment point for the base of the blades to connect with the generator shaft. The size of the rectangle varies depending on the design of the generator and generator shaft. Some generator designs may call for the blades to be attached to a disk or gear, which itself is fixed permanently to the shaft. In order to accomplish these blade templates at the desired locations around the disk template, mark where to drill holes through the actual steel pan, and attach the blades to the hub via nuts and bolts.

4., Mark and cut the construction paper blades so that they resemble airplane wings. In this work, it is ensured that small "tip" edge of the blade is flattened. This is done with the use of pen to write on the template to indicate the leading edge of the blade, which should be tapered and rounded out on the actual steel pan. The trailing edge is marked as well; the trailing edge is made to flatten out. Writing out notes on which part is the leading edge will help to keep the fabrication process organized. Once one blade design is finished, one can use it as a template for the others which guarantees the fabrication of nearly identical blades. Most systems will have three to four blades.

5., Cut off and round sharp corners with cutting tool, so that wind drag is reduced on the design template blades. The reciprocating saw will be used to cut along the diagonal line. This will shape the blades in a way as to increase their performance.

6., Drill a hole in the centre of the base of the blade. This hole will be used to secure the blades to the wind turbines hub. This is done by drilling a hole through the flange where each wind turbine blade will be placed, and attaching the blades by inserting a bolt through both the flange and the blade. The bolt is then secured by screwing a nut into place.

7., Machine is used to smoothen out the rough edges of the steel blade. The smoother the edge of the blades, the better.

8., The steel blade is then taken to the workshop for finishing as shown in Figure 1.

2.1.3 Assembling of wind turbine blade

In simple designs, this turbine blade is directly bolted to the hub. However, in more sophisticated designs, they are bolted to the pitch mechanism, which adjusts their angle of attack according to the wind speed to control her rotational speed. The pitch is itself bolted to the rotor shaft which drives the generator through a gearbox. Direct drive wind turbine, like ours is also called gearless, are constructed without a gear as stated earlier. Instead, the rotor shaft is attached directly to the generator which spins at the same speed as the blade.

2.2 The inverter

An inverter allows the use of 230V electrical appliances from a car battery or a solar battery. It must therefore supply a voltage that corresponds to an RMS of 230 Volts sine-wave like the household main supply or similar. The type of inverter used in this project is the pulse width modulated type with waveform as shown in Fig. 2:

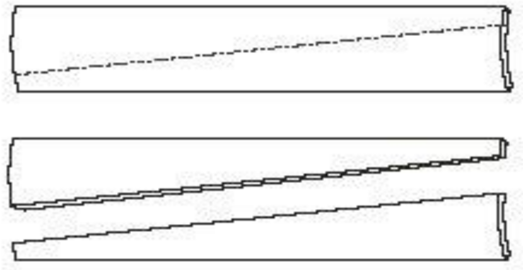

Fig.1: The steel blades after cutting (Image courtesy hydrogenappliances.com)

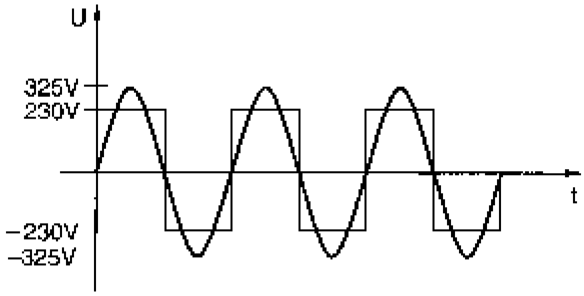

Fig.2: Sine-wave voltage and conventional square wave voltage with both 230 V RMS [18]

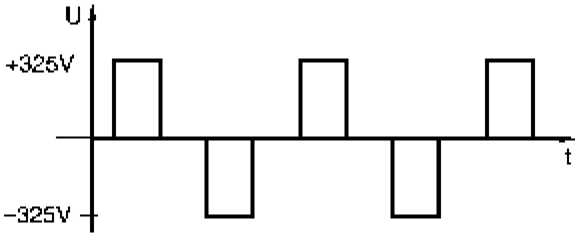

Fig. 3: Square wave voltage with duty cycle 25% for 230 V rms ("modified sine") [18]

2.2.1 Transformer Design

The main design considerations in a transformer are: The core size. The size of the core in a transformer depends on the volt-ampere rating, the relationship between the cross-sectional area and the center limb in an E-I type core is as in [19] given as:

Core area (a)= $1.25\sqrt{VA}\ cm^2$ = $1.25*\sqrt{\ }\ 1000$ = $39.52\ cm^2$, (1)

since the required rating according to the specification of the project is 1000VA. With this value, a type 8 EI core with tongue width 5.08 cm, the stack height will be 39.52/5.08= 7.8cm

To determine the size of the conductors required for the winding, the basic transformer equation given below is used.

$V = 4.44FaNB10^{-8}$ [14]. (2)

The ratio required to compute the number of turns is the "Turns per volt" at the specified flux density and frequency of 50Hz this is given by [14]

$$\frac{N}{V} = \frac{10^8}{4.44*50*a*B} \quad (3)$$

For (cold rolled grain oriented) core metal stamping B = 11500 gauss or 1.15 Tesla. Therefore, from [19],

Turns / Volt = $\frac{450450}{11500*a} \approx \frac{39}{a}$ (4)

Since a is calculated to be 39.52 then Turns per volt is 0.9873 ≈ 1 Turn per Volt.

The primary winding is to operate at 12V so number of turns is 12 transformers.

The primary of an inverting transformer has two winding switched on every half cycle so the total number of primary turns will be 24, and the secondary is to operate at 230V so the number of turns is 230.

2.2.2 Gauge Size of the windings

The power rating of the transformer = 1000VA.

For secondary at 230V,

Current density = 3 A/ m^2 .

Thus, $I = \frac{1000}{230} = 4.34A$. (5)

Current densities from 3.0/mm^2 to 4 A/mm^2 are used on industrial transformers. [20]

Cross sectional area of conductor $= \frac{Secondary\_Current}{CurrentDensity}$ (6)

Therefore, conductor area $= \frac{4.34A}{3A/mm^2} = 1.45mm^2$. (7)

Since Area of circle is п r^2 , then $r = \sqrt{\frac{A}{\pi}}$., Diameter

$$D = 2r = 2\sqrt{\frac{A}{\pi}} = 2\sqrt{\frac{1.45mm^2}{3.142}} = 1.36mm \quad (8)$$

From table of standard wire gauge [13] this value corresponds to 17 SWG.

For primary at 24V i.e. 12-0-12 winding

Current density =3 A/mm^2

Thus, $I = \frac{1000}{24} = 41.67A$

Cross sectional area of conductor $= \frac{Primary\_Current}{CurrentDensity}$. (9)

Therefore, conductor area $= \frac{41.67A}{3A/mm^2} = 13.89mm^2$. (10)

Diameter

$$D = 2r = 2\sqrt{\frac{A}{\pi}} = 2\sqrt{\frac{13.89mm^2}{3.142}} = 4.21mm \quad (11)$$

From table of standard wire gauge [4] this value corresponds to 8 SWG.

2.2.3 The pulse width modulation MOSFET based technique

This approach is to use MOSFET as its output drive device to ensure absence of secondary breakdown, eliminate thermal runaway, improve switching speed, reduce drive power such that it can be driven from gates and to be used in parallel for greater power capability. The SG3524A is the main integrated circuit **(**IC) which incorporates all the functions required in the construction of a regulating power supply, inverter, or switching regulator on a single chip. It can also be used as the control element for high-power-output applications. The SG3524 are designed for switching regulators of either polarity, transformer-coupled DC-to-DC converters, transformer-less voltage doubles, and polarity-converter applications employing fixed-frequency, pulse-width modulation (PWM) techniques. The complementary output allows either single-ended or push-pull application. Each device includes an on-chip regulator, error amplifier, programmable oscillator, pulse-steering flip-flop, two uncommitted pass transistors, a high-gain comparator, and current-limiting and shutdown circuitry.

Fig. 4 shows a functional block diagram of SG3524. The SG3524 is a fixed-frequency pulse-width-modulation (PWM) voltage-regulator control circuit. The regulator operates at a fixed frequency that is programmed by one timing resistor, R_T, and one timing capacitor, C_T. R_T establishes a constant charging current for C_T. This results in a linear voltage ramp at C_T, which is fed to the comparator, providing linear control of the output pulse duration (width) by the error amplifier. The SG3524 contains an onboard 5-V regulator that serves as a reference, as well as supplying the SG3524 internal regulator control circuitry. The internal reference voltage is divided externally by a resistor ladder network to provide a reference within the common-mode range of the error amplifier or an external reference can be used. A second resistor divider network senses the output and the error signal is amplified. This voltage is then compared to the linear voltage ramp at C_T. The resulting modulated pulse out of the high-gain comparator is then steered to the appropriate output pass transistor (Q1 or Q2) by the pulse-steering flip-flop, which is synchronously toggled by the oscillator output. The oscillator output pulse also serves as a blanking pulse to ensure both outputs are never on simultaneously during the transition times. The duration of the blanking pulse is controlled by the value of C_T. T

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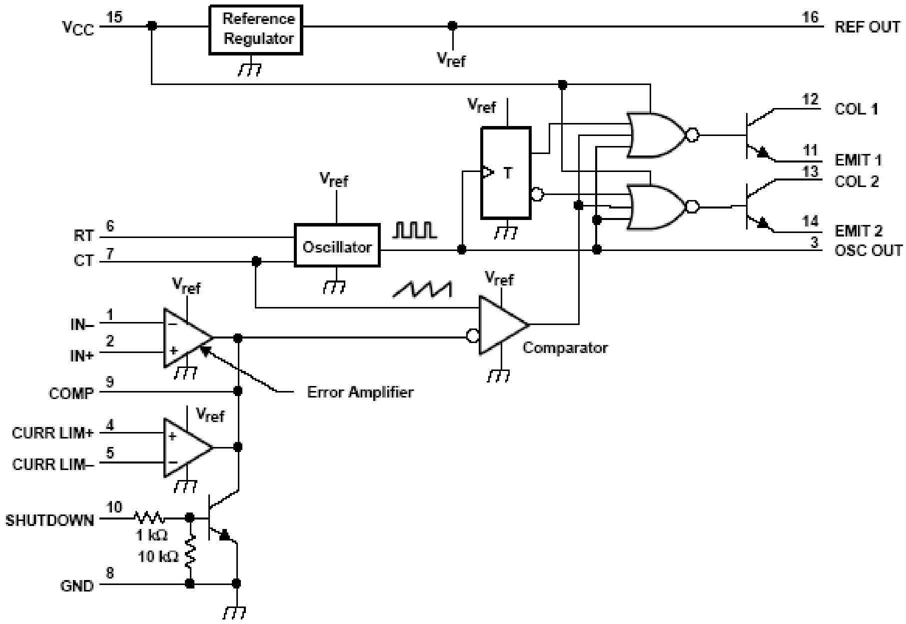


Fig.4: Functional block diagram of the SG3524

The regulator operates at a fixed frequency that is programmed by one timing resistor, R_T, and one timing capacitor, C_T. R_T establishes a constant charging current for C_T. This results in a linear voltage ramp at C_T, which is fed to the comparator, providing linear control of the output pulse duration (width) by the error amplifier. The SG3524 contains an onboard 5-V regulator that serves as a reference, as well as supplying the SG3524 internal regulator control circuitry. The internal reference voltage is divided externally by a resistor ladder network to provide a reference within the common-mode range of the error amplifier or an external reference can be used. A second resistor divider network senses the output and the error signal is amplified. This voltage is then compared to the linear voltage ramp at C_T. The resulting modulated pulse out of the high-gain comparator is then steered to the appropriate output pass transistor (Q1 or Q2) by the pulse-steering flip-flop, which is synchronously toggled by the oscillator output. The oscillator output pulse also serves as a blanking pulse to ensure both outputs are never on simultaneously during the transition times. The duration of the blanking pulse is controlled by the value of C_T. The outputs may be applied in a push-pull configuration in which their frequency is one-half that of the base oscillator, or paralleled for single-ended applications in which the frequency is equal to that of the oscillator. The output of the error amplifier shares a common input to the comparator with the current-limiting and shut-down circuitry, and can be overridden by signals from either of these inputs. This common point is pinned out externally via the COMP pin, which can be employed to either control the gain of the error amplifier or to compensate it. In addition, the COMP pin can be used to provide additional control to the regulator [16].

2.2.4 Designing the Oscillator

The oscillator controls the frequency of the SG3524 and is programmed by R_T and C_T,

$$f = \frac{1.3}{R_T C_T} \qquad (12)$$

where R_T is in KΩ, C_T is in µF, and f is in kHz. Practical values of C_T, fall between 0.001 µF and 0.1 µF. Practical values of R_T, fall between 1.8 KΩ and 100 KΩ. This results in a frequency range typically from 130 Hz to 722 KHz.

The expected frequency of operation is 50 HZ; hence, the value of R must be determined. Since 0.1µF is readily available and it falls within the range of operation of the IC. The value of R can be calculated as

$$R_t = \frac{1.3}{(0.1*10^6)x50}\,\Omega,\ R_T = 260000\Omega. \qquad (13)$$

With this value, a variable resistor of 50KΩ in series with a 230K-fixed resistor to obtain accurate setting of frequency at the mid-range of the variable resistor

i.e. $230 + \frac{50}{2} = 255 \approx 260\text{K}\Omega.$

2.2.5 Feedback network for determination of state of output and auto adjusting pulse width

To accomplish proper control of the pulse width yielding a stable output voltage independent of load and battery voltage, it is necessary to obtain an instantaneous sample of the output voltage, which will be processed and used to control the error amplifier in the SG3524 IC.

This is achieved by using a rectifier in conjunction with a voltage divider network and a buffer (OPTO IC 4N35). This network generates an error signal, which continuously adjust the pulse width to give a constant mean voltage. The error amplifier in the IC is an operational amplifier (op-amp) hence, to control the pulse width, the non-inverting input is biased with a fixed voltage. This is obtained from the 5V reference output and divided into half using a divider network R3 and R4(4.7K each) which yields 2.5V. The inverting input is connected to the output of the 4N35 opto-IC to accurately adjust the pulse width, and a potential divider which consist of a fixed resistor and a variable resistor.

The op-amp input consists of a diode and when forward biased draws current of 0.85Ma, and the forward voltage drop is 1V according to manufacturers datasheet. 1.2V is expected across the rectifier (0.6V*2 since two diodes are forward biased in each half cycle)

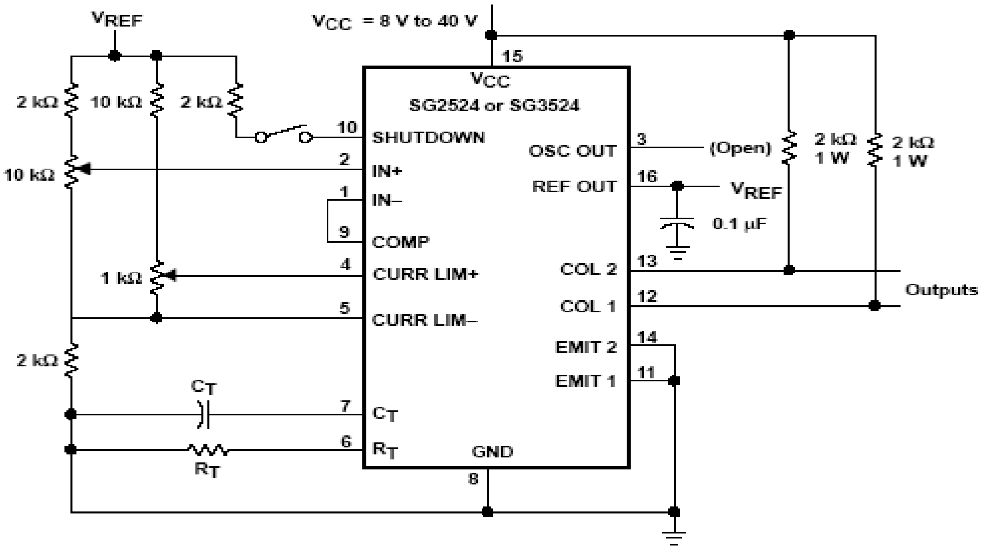


Fig.5: Basic test circuits for the oscillator

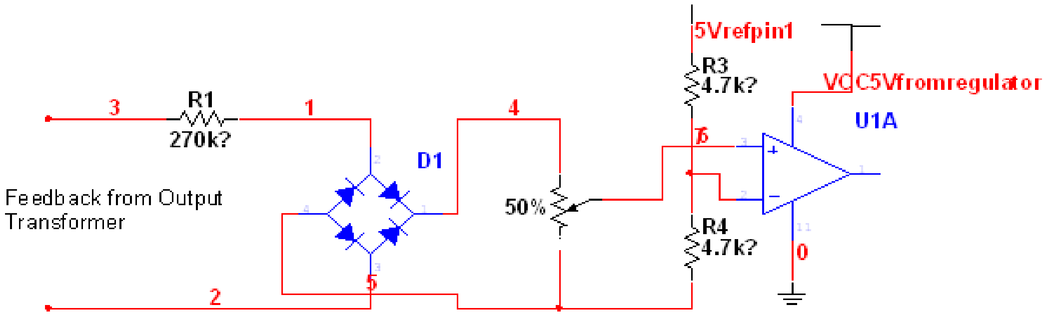
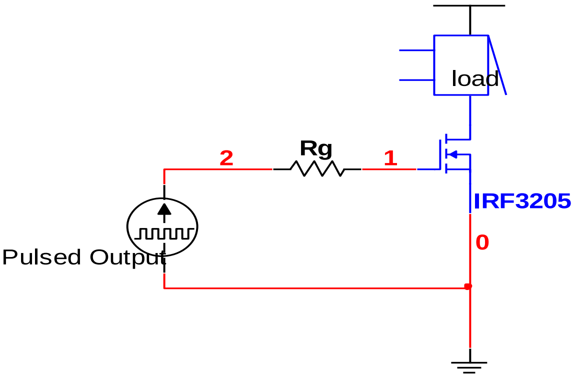


Fig.6: Feedback circuit for control of pulse width



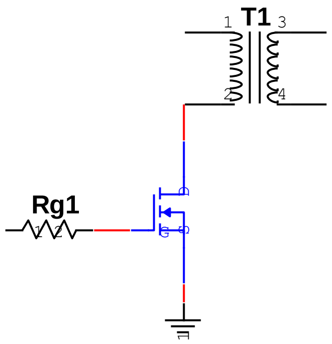


Fig.7: MOSFET Used as a switch

Fig.8: MOSFET used to Pulse current into the transformer

The value of the resistor required is

$$\frac{(230-1-1.2)}{0.85*10^{-3}} = 268*10^{3} \cong 270K\Omega \qquad (14)$$

2.2.6 The MOSFET Driver

The output of the oscillator is of low amplitude and can not be used to switch large current into the transformer. There is need to incorporate an electronic switch to perform the switching function at this stage, one of such electronic switch with very simple circuitry is the MOSFET. A simple MOSFET drive is as shown below.

To determine the type of MOSFET to choose, the voltage rating, current, and power must be put into consideration. Since the inverter is to operate at 12V and the power is 1000VA. For simplicity, a MOSFET with high power rating such as the

IRF3205 with power dissipation 200W, VDSS =55V and Id=110A can be used [19].

Number of parallel transistors =

$$\frac{Inverter\_Rated\_Output}{Transistor\_Power\_Rating} = \frac{1000}{200} = 5 \quad . (15)$$

The MOSFET drive will therefore contain five IRF3205 MOSFET per Half (i.e. 5 pairs =10 MOSFET)

2.6.7 The Design of the Inverter and display Controller

The work of the controller is to monitor the status of the battery, shutdown the inverter when the battery is low, and display the status of the system using the LCD. The controller operates using the basic flow chart shown below:

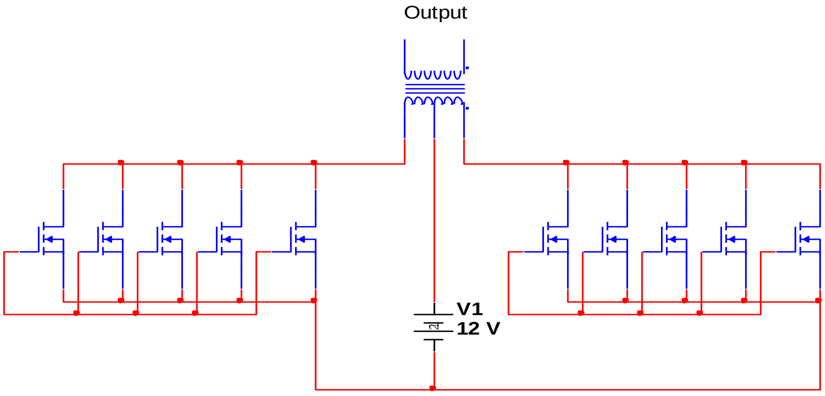


Fig. 9: Five MOSFET connected in parallel to deliver 1000W

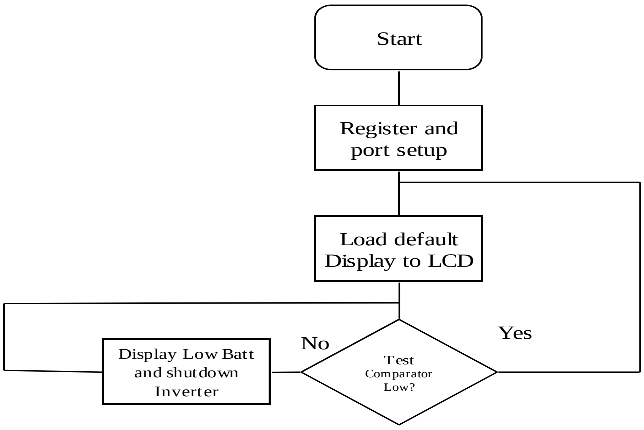


Fig.10: Flowchart for the controller circuit.

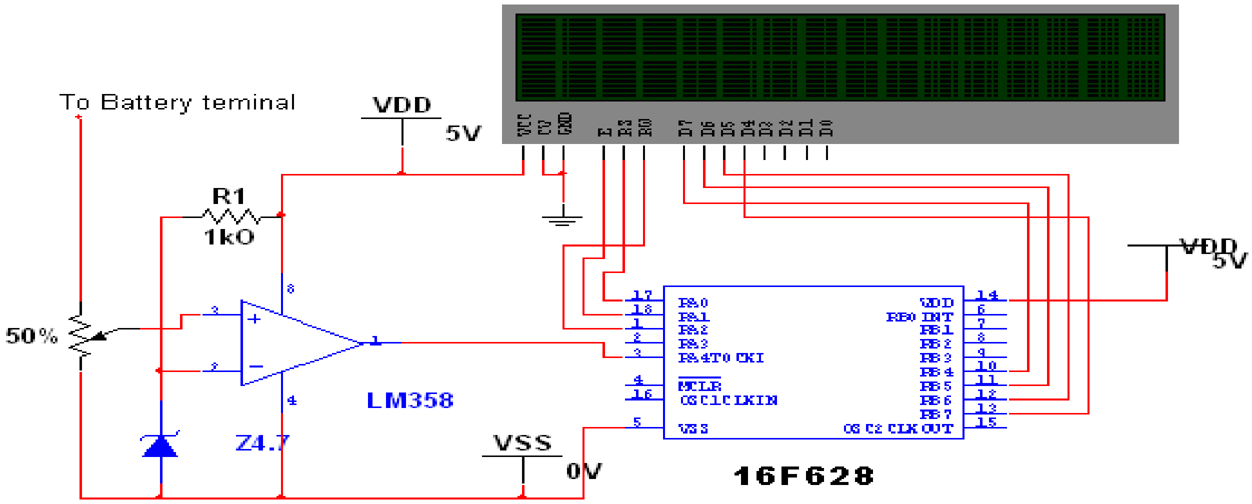


Fig.11: Circuit diagram for the 16F628 controller circuit.

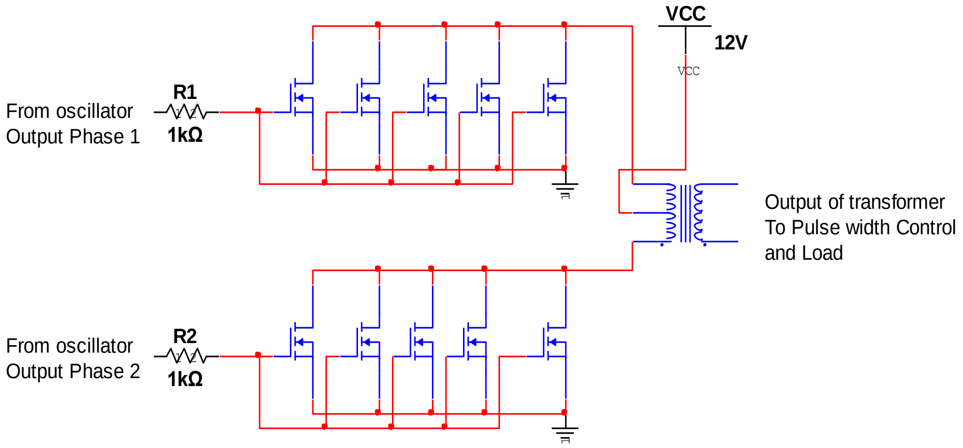


Fig.12: Complete Schematic diagram of the inverter (MOSFET amplifier circuit)

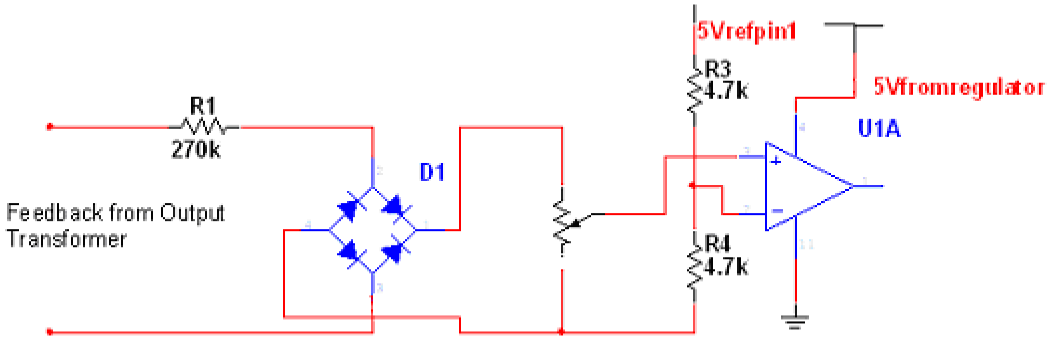


Fig.13: Feedback circuit

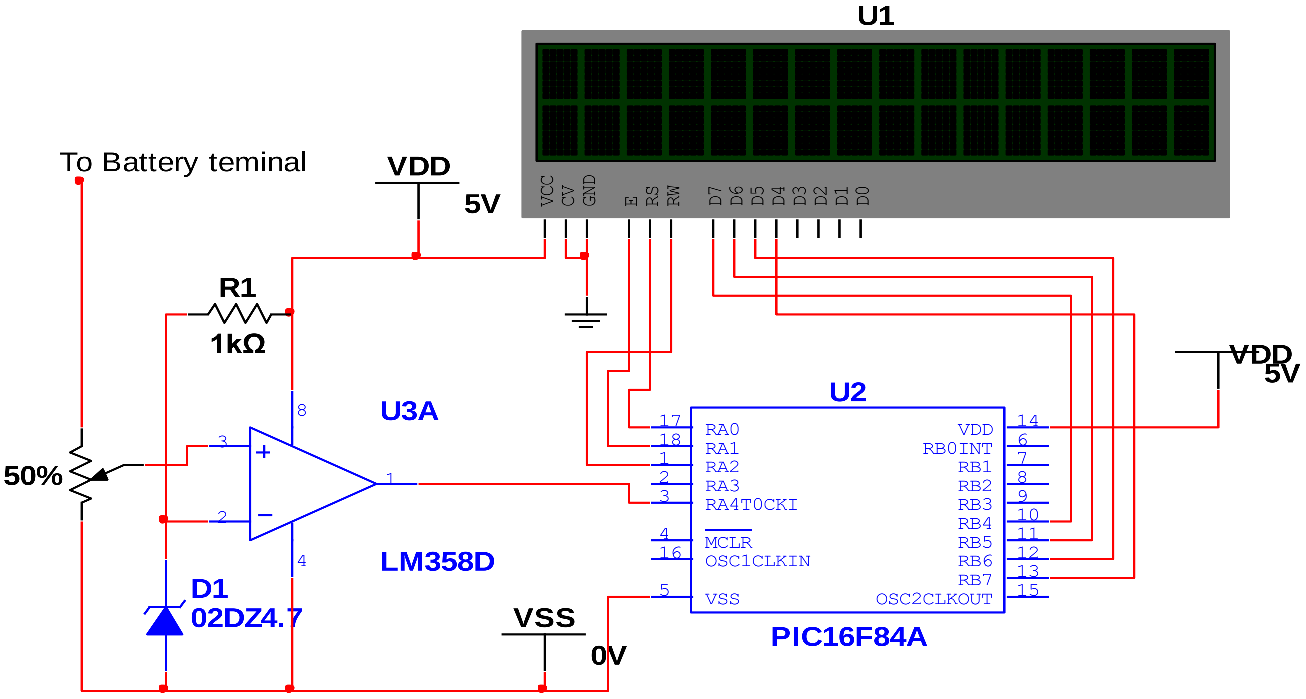


Fig.14: Complete Schematic diagram of the inverter

2.6.8 Determination of Battery size for storage of energy from the wind generator

The major concern here is how much energy is made available from the generator? The answer to this question will lead to the amount of storage that should be made available to receive this energy.

The type of generator chosen will deliver 12V (the system voltage) at its rated maximum current. Therefore, since the motor nameplate shows the maximum current of 6A, assume the turbine will rotate and produce high enough voltage to charge the battery for an average period of 10 hrs in a day.

The total energy generated will be

$$E = I * V * T = 12V * 5A * 10Hrs = 600 Wattsperday \quad (16)$$

This is approximately 18KWatts per Month and 220KWatts per year.

To determine the AH rating of the battery to receive this energy

$$AH_{Rating} = \frac{Energy}{Voltage} = \frac{600}{12} = 50AH \quad (17)$$

This assumption and calculation led to the purchase of a 57.2 AH battery since it is the available size in the market and it is bigger than the calculated value which is better for the system.

3. TESTING

The following parts were subjected to test:

- Reaction of the wind turbine to low and high wind speeds
- The output voltage of the Generator
- The charge current delivered to the battery
- The output voltage and frequency of the inverter

4. RESULTS

- With very low wind speed it was observed that the wind turbine blades were able to pick up and rotate so the objective of the work which is to convert wind energy to mechanical has been achieved.
- The generator output measured between 12V to 15V while the turbine spine on no load.
- The charge current to the battery varied from 4A to 7A depending on the wind speed.
- The output voltage of the inverter was measured using an AC voltmeter yielding 230V at 50Hz.
- The inverter was allowed to run on load for several hours without charging from the turbine and when the battery voltage drop to 10.2V shutdown was initiated by the controller to protect the battery from deep discharge.

Table 1 shows the discharge characteristics of a battery. As can be seen from the table, even as the battery is being used up, the output voltage remains constant.

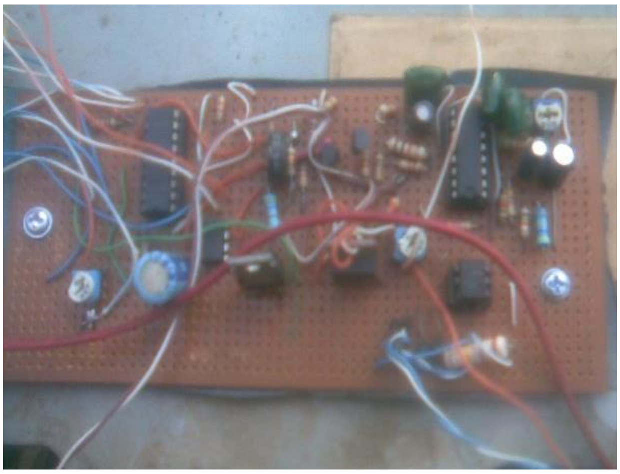


Fig.15: Picture of the Oscillator after assembly on Vero-board

Fig.16: Picture of the transformer

Fig.17: Picture of LCD showing the default display OOU wind Power 230V 50Hz

Table 1. Reading taken on 21/10/2019, illustrating discharge characteristic for the Battery in use on a 60W load.

Time of the Day	Voltage (V)	Current (mA)
8:00 AM	12.3	5.01
8:30 AM	12.28	5.03
9:00 AM	12.26	5.04
9:30 AM	12.24	5.06
10:00 AM	12.22	5.07
10:30 AM	12.12	5.08
11:00 AM	11.99	5.09
11:30 AM	11.93	5.11
12:00 PM	11.89	5.12
12:30 PM	11.82	5.13
1:00 PM	11.74	5.14
1:30 PM	11.64	5.15
2:00 PM	11.55	5.16
2:30 PM	11.45	5.18
3:00 PM	11.3	5.2
3:30 PM	11.12	5.22
4:00 PM	10.85	5.21
4:30 PM	10.45	5.22
5:00 PM	10.43	5.28

Table 2. Test Result showing Wind speed, Turbine Speed and Output Voltage

Time of the Day	Wind Speed (m/s)	Turbine Speed (RPM)	Output Voltage (V)
8:00 AM	5.1607	410.88	10.70
8:30 AM	5.6429	449.28	11.70
9:00 AM	6.077	483.84	12.60
9:30 AM	6.3664	506.88	13.2
10:00 AM	6.4628	514.56	13.4
10:30 AM	6.2699	499.2	13
11:00 AM	6.1734	491.52	12.8
11:30 AM	6.0288	480	12.5
12:00 PM	5.7394	456.96	11.9
12:30 PM	4.1478	330.24	8.6
1:00 PM	5.4018	430.08	11.2
1:30 PM	4.8305	384.6	10
2:00 PM	4.5336	360.96	9.4
2:30 PM	4.6783	372.48	9.7
3:00 PM	5.2088	414.72	10.8
3:30 PM	6.077	483.84	12.6
4:00 PM	6.294	501.12	13.05
4:30 PM	4.0513	322.56	8.4
5:00 PM	4.8285	384.44	9.1

4. DISCUSSION

The result obtained shows that the design procedure and construction details are quite effective, the height of the tower is good enough as there is no obstruction at the installation site. Furthermore, the choice of the generator has proven to be a good one since the battery is able to charge with low wind speed. The inverter design is excellent yielding an output that is an approximation of the normal mains supply required for any AC load. The pulse width modulation system allows perfect control of the R.M.S. of the wave to maintain peak power for load.

5. CONCLUSION

The result analysis shows that the blade design is adequate for the project work, the operation of the inverter and its control characteristics is a justification for the design calculations. Finally, the charging and load control properties of the generator and the inverter shows that the aim of the project has been accomplished.

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