AC-Grid Generation using Dual-Input Hybrid Inverter Circuit

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Abstract- **Whilst a normal inverter converts the DC voltage into AC voltage, an off grid inverter occupies input from either solar panel or wind turbine. This paper is about the design and simulation of a bi-input inverter using PV and Wind power system. The overall design will result in a regulated AC output load for AC grid connected system. This paper also discusses on two circuits which is charge controller and inverter. It is found that regulated output AC voltage level of 110 V and current 13 A have been successfully simulated using MULTISIM Power Pro Edition 12.0 which is applicable for national 50-Hz transmission grid line.**

I. INTRODUCTION

The need for a clean, environment friendly, renewable energy source is high. Electricity is one of the greatest creation by human beings, and one of the important energy for our daily life usage. There are two methods to generate electricity. The first method is by using non-renewable source such as coal, gas and petroleum. The second method is by using renewable source such as hydropower, wind power and solar power. As conventional sources of energy are rapidly depleting and the cost of energy is rising, photovoltaic and wind energy become promising alternative sources. Three are basic systems for an inverter; the DC electric generation side (solar array, wind turbine), controller, DC battery, and finally the inverter. Inverter is used to convert DC (direct current) source into AC (alternating current) source [1]. The design of an inverter by using a clean form of energy source will always give positive impact to the environment. This is because the output of the two input inverter does not contain smoke or other chemical effluents.

The bi-input inverter is more efficient than a single input inverter. This is because the combination of the two input causes more current flow to the battery, which allows faster recharging time of the battery [2]. Charge controller is chosen as the controller for this system. Current produced by solar array or wind turbine will be used to charge the battery. Solar inverter will not work efficiently at night and wind turbine inverter will not work efficiently when there is less wind. Hence, the design of a bi-input inverter is the solution. A bi-input inverter is the combination of Photovoltaic Array and Wind Turbine into an inverter for AC grid application [3].

A. *Photovoltaic Array*

PV array is called Photovoltaic Array. Combination of solar cell is called Photovoltaic Array. Solar cells are combined to form Photovoltaic Array to generate more DC voltage. PV array will convert sunlight into DC voltage [4].

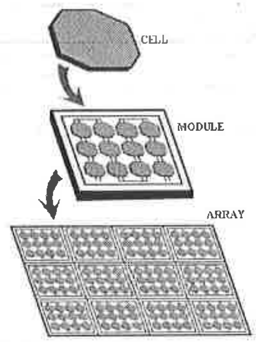

Fig. 1. Formation of photovoltaic array [5]

Fig. 1 shows the formation of Photovoltaic Array. From here, it is seen that solar cell will form solar module when combined. For bigger output, solar module combined will form solar array or Photovoltaic Array [6].

B. *Wind Turbine*

Fig. 2. Wind turbine model [6]

Fig. 2 shows the wind turbine model. Wind turbine generates electricity from the wind that spins the turbine blade [7-9]. The generator inside the wind turbine will spin and generate DC voltage.

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II. METHODOLOGY

The project focuses on generating a stable output voltage out of two combined unstable inputs, which is sun light and wind. The design phase of the charge controller was first conducted after which it was then simulated. The charge controller and hybrid inverter circuits were integrated for AC generation at the load. The experimental phase is in progress for validation.

A. Control System

In order to control the charge going into the battery, a controller is needed. Important functions of battery charge controller for this system are to [10]:

- prevent battery over charged by limiting the current supplied to the battery by the PV array or wind turbine when the battery becomes fully charged.
- prevent battery over discharged by connecting the battery to PV array and wind turbine when the battery reaches low state of charge.

The ultimate goal is to get a stable oscillating output voltage of 50-60 Hz frequency, with alternating 110 V and 13 A, while keeping the battery in a good condition. The NiMH battery is used because it can be overcharged with 20 % more energy than its nominal capacity [11].

B. Inverter System

For a two input inverter system, where wind and solar energy are not consistent, the output of the system will not be always stable. Therefore, there is a need to make sure that the output will be regulated to be used for electrical appliances.

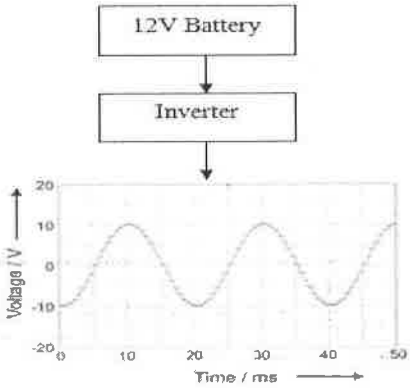

Fig. 3. Block diagram of an inverter

In Fig. 3, 12V DC battery will be connected to the input panel of an inverter. Inverter will convert the DC voltage to a required AC voltage. In this case, the output will be a pure sine wave signal with 50-60 Hz frequency, with 110 V AC voltage and 13 A AC current [12]

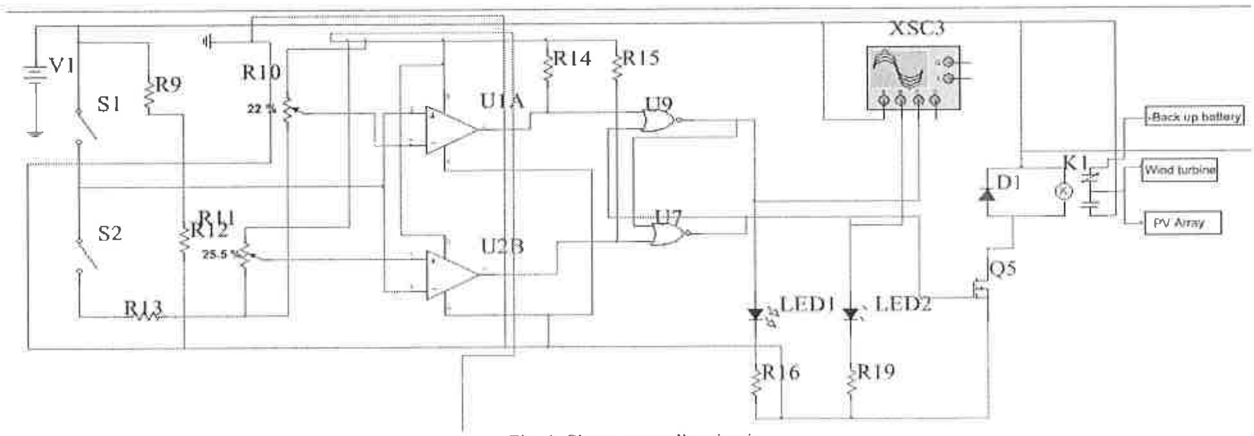

Fig. 4. Charge controller circuit

C. Charge Controller Design

Fig. 4 shows the circuit diagram for the charge controller which will be simulated. There are two input sources, which is coming from the solar panel and wind turbine. The tripping point for the relay K1 to start charging the battery is 12 V, which means, when the voltage of the battery is at 12 V, the relay will trip to channel the current into the battery [13]. On the other hand, when the voltage of the battery reaches 12.2 V, the relay will trip to the backup battery, and stop charging the main battery. LED1 and LED2 will be used for indication purposes. Here, the inverter will be connected to the main battery.

D. Inverter Design

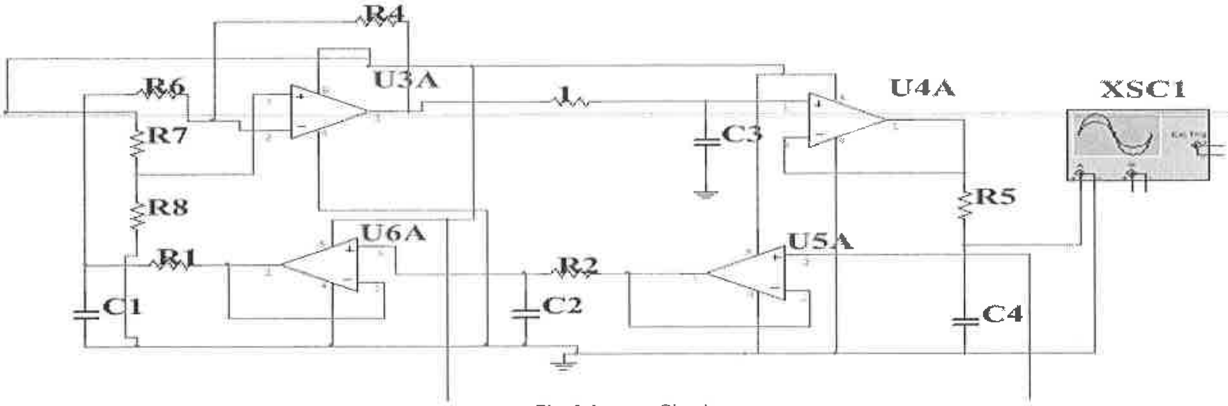

Fig. 5. Inverter Circuit

Fig. 5 shows the circuit diagram for the inverter. This is a Bubba oscillator circuit. Bubba oscillator circuit can produce a stable output voltage with 53.1 Hz frequency. Frequency calculation was done for the components in the circuit to achieve 53.1 Hz output frequency based on Eq. (1)

$$f = \frac{1}{2 \times \pi \times R \times C} \quad (1)$$

where f is the frequency, R and C are the corresponding resistor and capacitor value in Figure 7. R4 must be a high gain resistor [14] so that the gain A will be 4. R7 and R8 forms a voltage divider circuit to give 6 V to the positive node of U3A op amp.

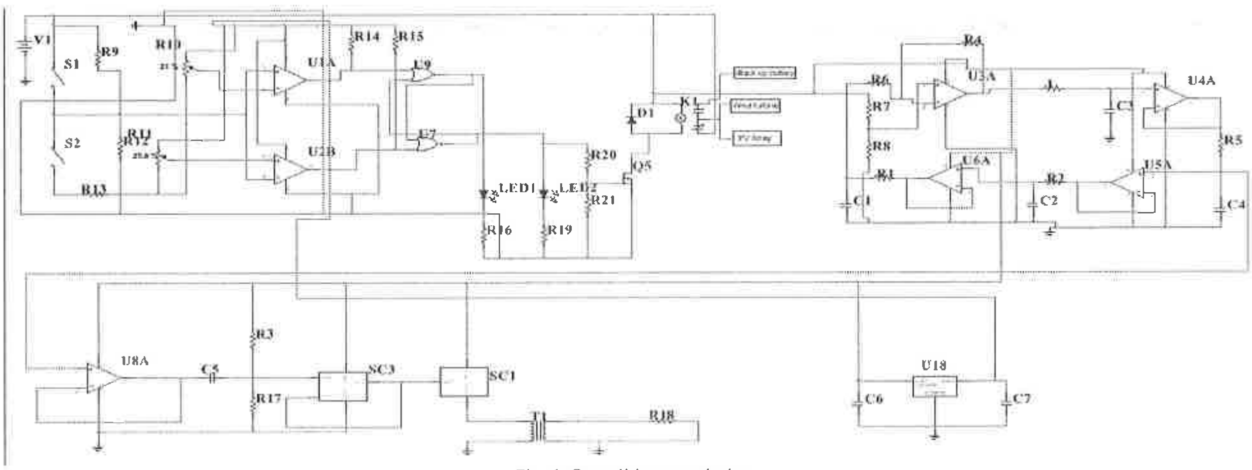

Fig. 6. Overall inverter design

E. Overall Design

Fig. 6 shows the overall inverter design. The inverter circuit is connected to voltage follower circuit. Voltage follower circuit is designed to make sure that the step-up transformer does not draw current from the oscillator. A sub-circuit which contains parallel connected op amps resembles a big voltage follower circuit.

There is also a sub-circuit contains 67 Darlington pairs connected in parallel. The main reason is to increase the output current to a higher level, so that during the step-up process, the current will remain at a desired level at the output, which is at 13 A while maintaining AC output voltage of 100 V. The amount of Darlington pairs to be added can vary according to the required output current.

Fig. 7 shows the connection for parallel connected voltage follower. The voltage follower with an ideal op amp gives simply because the input impedance of the op amp is very high, giving effective isolation of the output from the signal source [15]. The output draws very little power from the signal source, avoiding "loading" effects. This circuit is a useful first stage for the inverter circuit. This is because, without using the voltage follower circuit, the sine wave at the output part of the inverter becomes less in magnitude with reference to time.

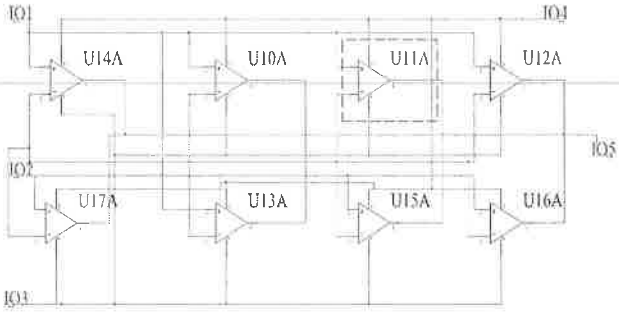

Fig. 7. Voltage follower sub-circuit contents

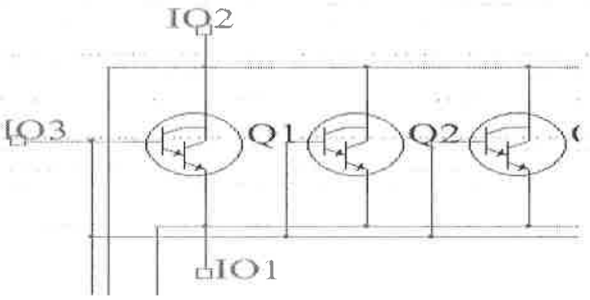

Fig. 8. Darlington pairs sub-circuit

Fig. 8 shows the content of the Darlington pair sub-circuit. Darlington pairs are used to increase the current of the signal [16]-[17]. This is two transistors connected together to form one Darlington transistor so that the current amplified by the first is amplified further by the second transistor. The overall current gain is equal to the two individual gains multiplied together [16].

The overall DC or low frequency current gain for the Darlington pair will be as Eq. (2),

$$\frac{I_{out}}{I_{in}} = \beta 1 + \beta 2 + \beta 1 \times \beta 2 \qquad (2)$$

where $\beta 1$ and $\beta 2$ are the gain for both transistors in the Darlington pair. Thus at low frequencies, the Darlington pair is approximately equivalent to a single transistor with a current gain greater than $\beta 2$.

III. RESULTS & DISCUSSIONS

The output of the charge controller and inverter will be discussed and analyzed. For the charge controller, the charging and discharging phase will be discussed. For the inverter, the improvement done and the corresponding result will be discussed.

A. Charging Phase

Fig. 9 shows the result obtained from the simulation on charge controller in Fig. 2. The tripping point for the charge controller was set to be 12 V and 12.2 V. Hence, when the voltage of the battery is 10 V, channel C receives 5 V and channel B receives 0 V. When the 'gate' voltage of the MOSFET is 0 V, the relay will not trip. As a result, the current generated by wind turbine and PV array will be directed to rechargeable battery (main battery). Hence, the battery will remain in charged condition.

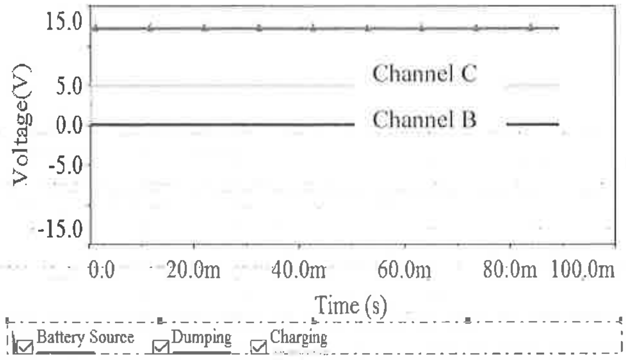

Fig. 9. Result for charging cycle

B. Discharging Phase

Fig. 10 shows the result for the discharging phase of the main battery. Now, the voltage of the battery was set at 15V. From here, it can be seen that channel C receives 0 V and channel B receives 5 V. When the 'gate' voltage of the MOSFET is 5 V, the relay will trip. As a result, the current generated by wind turbine and PV array will be directed to the backup battery. Hence, the main battery will be in discharging mode. From both results, the charge controller does the work on deciding the charging and discharging point for the battery.

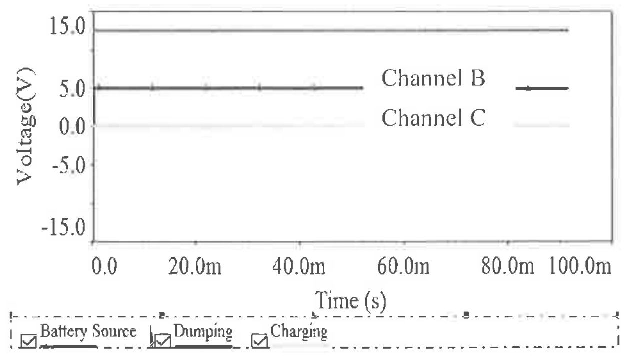

Fig. 10. Result for discharging cycle

C. *Inverter Analysis*

The inverter circuit in Fig. 5 has been analyzed to get the output. A total of 67 Darlington pairs have been added in this circuit. Finally, the targeted result was achieved where the output load is 110 V AC and 13 A AC. This should be enough to be used as a power point in houses for small appliances.

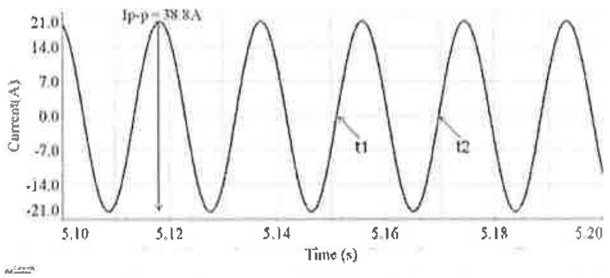

Fig. 11. Transient response for output current

Fig. 11 shows the transient response for output current. The current swings from +19.5 A to -19.5 A, hence, the peak-to-peak current is 38.8 A. The RMS current can be calculated and the measured current is 13.7 A AC.

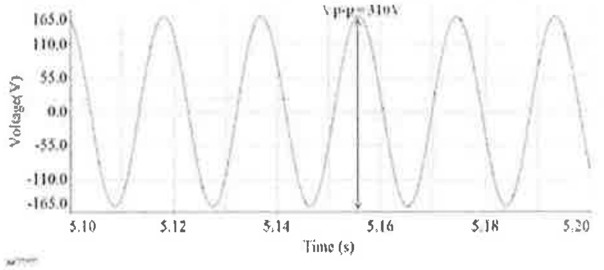

Fig. 12. Transient response for output voltage

Fig. 12 shows the transient response for output voltage. The voltage swings from +155 V to -155 V. As a result, the peak-to-peak voltage is 310 V. The RMS voltage is measured as 109 V AC.

IV. CONCLUSION

Based on the simulation results, it is shown that the proposed inverter circuit configuration has proven its functionality to generate a stable AC 110V / 13A output, which is indeed suitable for grid network application at 50 Hz. Experimental verification would be the subsequent step to justify the simulation results.

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REFERENCES

[1] V. Yuvaraj, R.Rozario, & S.N. Deepa, "Implementation and control of multi input power converter for grid connected hybrid renewable energy generation system", *Student Pulse Academic Journal*, Vol. 3, No. 6, pp. 2-4, June 2011.

[2] - "Solar powers is the future.com", Retrieved April 5, 2012 from http://www.solarpoweristhefuture.com/how-to-charge-a-battery-with-a-solar-panel.shtml

[3] Selvaraj, J.; Rahim, N. A., "Multilevel Inverter for Grid-Connected PV System Employing Digital PI Controller", *IEEE Transactions on Industrial Electronics*, Vol. 56, Issue 1, pp. 149-158, January 2009

[4] Narudin Abd. Rahim, Senior Member, IEE, Krismadinata, Student Member, IEEE, & Jeyraj Selvaraj, "Single-Phase Seven-Level Grid-Connected Inverter for Photovoltaic System", *IEEE Transactions on Industrial Electronics 2011*, Vol.58, No.6, pp 2435, Jun 2011.

[5] I. Daut, M. Irwanto, Y.M Irwan, N.Gomesh, Rosnazri & N.S Ahmad, "Potential of solar radiation and wind speed for photovoltaic and wind power hybrid generation in Perlis, Northern Malaysia", *The 5th International Power Engineering and Optimization Conference*, pp. 148-152, 2011

[6] A. Itagaki, H. Okamura & M. Yamada, " Preparation of Meteorological Data Set Throughout Japan For Suitable Design of PV Systems", *3rd World Conference on Photovoltaic Energy Conversion*, pp: 2074 – 2077, 2003

[7] S.A. Ahmed, "Wind energy as a potential generation source at Ras Benas, Egypt", *Renewable and Sustainable Energy Reviews*, Vol.14, pp. 2167-2173, 2010

[8] Chaniago, K.; Selvaraj, J.; Rahim, N.A., "Implementation of Single-Phase Grid Connected Inverter Using TMS320F2812", *3rd IEEE Conference on Industrial Electronics and Application, Singapore*, pp. 1498-1502, 3-5 June 2008.

[9] R.S Bientz, "Development of Hybrid Photovoltaic-Wind System for Academic Purposes", *ISES 2005 Solar World Congress, Orlando, FL. USA*, pp. 32, 2005.

[10] Nur Juwaina Ayuni BT.Mohd. "Photovoltaic charge controller", PhD thesis, Universiti Malaysia Pahang, May 2009.

[11] – "Batteries for Mobile Robots", Retrieved August 8, 2012 from http://robocup.mi.fu-berlin.de/buch/chap6/ComparisonBattery.html

[12] N. N. Bhargava and D. C. Kulshreshtha. "Basic Electronics & Linear Circuits" Tata McGraw-Hill Education, p. 86. ISBN 978-0-07-451965-3

[13] M. Davis, "How I home built an electricity producing Wind turbine", Retrieved March 20, 2012 from http://www.mdpub.com/Wind_Turbine/

[14] R. Manchini, R. Palmer, "Sine Wave Oscillator", *Texas Instruments, Dallas, Texas*, SLOA060, March 2001.

[15] -, "Voltage Follower – Non-Inverting amplifier with unity gain", Retrieved August 7 from http://terpconnect.umd.edu/~toh/ElectroSim/VoltageFollower.html

[16] B. Pandey, S. Srivastave, S.N Tiwari, J. Singh & S.N Shukla, "Qualitative analysis of small signal modified Sziklai pair amplifier", *Indian journal of pure an applied physics*, Vol.50, pp 272-276, April 2012.

[17] D. A. Hodges, "Darlington's contribution to transistor circuit design", *IEEE Transactions On Circuits and Systems-I: Fundamental Theory and Application*, vol.46, Iss. 1, pp. 102-104, Jan 1999.