International Journal of Engineering Innovation & Research
Volume 1, Issue 6, ISSN : 2277 – 5668

Analysis of Protection Scheme for a Battery Charger

Dr. J. C. Onuegbu
Department of Electrical Engineering
Nnamdi Azikiwe University, Awka, Nigeria
onuegbujo@yahoo.com

Dr. E. A. Anazia
Department of Electrical Engineering
Nnamdi Azikiwe University, Awka, Nigeria

***Abstract* – The paper took an indept analysis of two charge circuits and introduced a new model. The need to examine the properties of these charging circuits is in line with the need to pay more attention to harnessing the abundant renewable energy sources around us. Much attention was given to protection mechanisms necessary for the preservation of the life of the battery during storage, when in use and during the process of charging. The use of the model charger introduced in figure four has given reasonable comfort in the use the battery as an alternative energy source in homes and in the industry. The paper is aimed at providing automatic charging device that will be more convenient in application. This was achieved by incorporating three relays that ensured accurate functionality of the various protection circuits in the charger. The result is that the charge time for any battery can be predicted for the charging device and with the light and sound interfaces; the performance of the battery charger can be monitored. Human error in battery handling has been put under strict control.**

***Keywords* – Battery charger, transformer, booster charging, charge protection.**

I. Introduction to Battery Operation

A battery (accumulator) begins to discharge when its terminals consisting of positive and negative poles are connected to an external load. For lead IV oxide batteries, chemical reaction takes place both on the positive and negative poles.

$$PbO_2+2H_2SO_4+Pb \leftrightarrow 2PbSO_4+2H_2O \qquad (1)$$

where the products are lead II tetraoxosulphate VI and water. When the battery is fully charged, the positive or anode is PbO_2 and on the negative plate (the cathode) is Pb. The reversible reaction that takes place on the poles are

$$PbSO_4+SO_4+2H_2 \leftrightarrow PbO_2+2H_2SO_4 \qquad (2)$$

(at the anode),

and $$PbSO_4+H_2 \leftrightarrow Pb + H_2SO_4 \qquad (3)$$

(at the cathode).

The result is that the concentration of the electrolyte decreases as a result of the discharge and consequently the voltage on the poles of the battery reduces. Voltage reduces faster as more current is being drawn from the battery. The explanation to this is that during the discharge of high current at a relatively small moment of time, the amount of tetraoxosulphate VI diffused into the active mass of the positive pole will not be enough due to the delay in the formation of Lead IV oxide [1]. The Lead IV tetraoxosulphate VI which is a by-product of the reversible reaction then blocks the passage of ion into the active mass of the battery. Battery discharge changes the capacitance of the battery determined by the discharge current and the duration. Figure 1 illustrates the rate of discharge of an accumulator at various levels of voltage. Charging of accumulator is done using direct current voltage.

Direct current can be obtained from dc generator, from ac rectified voltage or from a battery bank. The most important thing is that the charging voltage must be higher than the battery e.m.f. in order to reverse the internal movement of the ions [2]. By this, the reaction of equation (1) is read from right to left. In equation (1), lead sulphate on both positive (anode) and negative (cathode) plates is reactivated, where lead (II) Oxide moves to the positive plate and on the negative plate will be pure lead metal to form $2PbSO_4$ (lead sulphate). As the charging continues, the concentration of the electrolyte increases leading to the increase in the charging rate and consequently the accumulator voltage increases. Towards the end of the charging process, that is when most of the lead sulphate must have been reactivated, there comes the process of electrolysis of water, in which hydrogen gas begins to liberate from the negative plate while oxygen liberates from the positive plate [3]. Liberation of gas begins at a voltage of 2.3 Volts per plate or 13.8V for a 6-plates 12Volts battery. Charging circuit should be disconnected at a voltage range of (13.8 – 14.5) volts [1, 2].

Battery discharge is a constant loss of ions as a result of chemical energy conserved in the accumulator caused by chemical action on the battery plates. The reaction that leads to the ionic loss is caused by mixture of metals in the active mass of the plates. Battery self discharge takes place during open circuit, during charging or when in use. In order that a battery is ready to take up load at any moment, there is need to compensate these capacitive losses by injecting a stabilizing voltage of about 2.15 – 2.25 Volts per plate. This can be done using rectified voltage from silicon made power transistor. It is observed that a new battery losses about 0.3% of its capacitance every day due to self discharge [2]. The voltage from this power transistor will maintain the stabilizing voltage of the battery and not allow the voltage to exceed the storage value. After three months from the day of maintenance charge of the battery, it should be switched over to full charge using a voltage of 2.3 – 2.35 Volts per plate until the density of the electrolyte reaches about 1.2 – 1.21 g/cm^3 on each battery compartment. The time for full charge should not be less than 6 hours. The density of each compartment must be measured separately because their rate of discharge is not the same but depends on accumulator temperature or exposure to sunlight.

International Journal of Engineering Innovation & Research
Volume 1, Issue 6, ISSN : 2277 – 5668

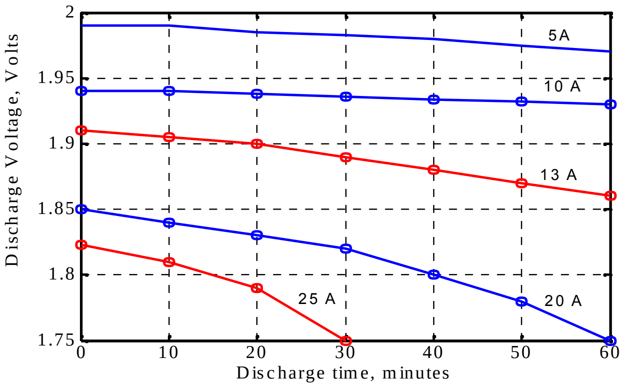

Fig.1. Battery discharge rate at various levels of load

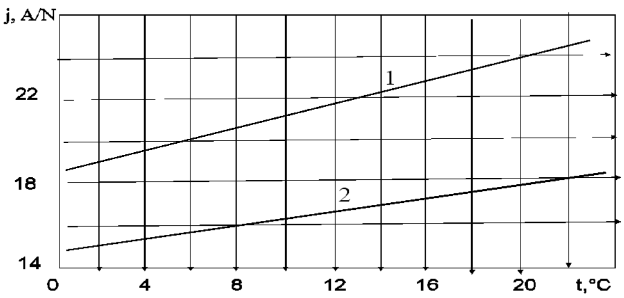

Fig.2. Dependent of discharge current on temperature of electrolyte for (1) ½-hour and (2) 1-hour respectively

If n be the number of plates of the battery, V_c be the charge voltage and V_p is the plate voltage, then for any number of plates, the charge voltage becomes

$$V_c = nV_p \quad (4)$$

V_c can be taken between 2.3 – 2.7 Volts for one battery plate. The range of charge voltage will be guided by the requirements of the charge control devices. This is why a battery charging transformer must contain multiple taps for voltage regulation [4]; bearing in mind that charge voltage must always be greater than the voltage of the battery being charged. Over charge or under charge must be detected and switched off before it causes irreparable damage to the battery [5]. When a battery is connected to a source voltage lower than itself, there will be a current flow reversal and the battery will discharge almost completely and grossly lower the life expectancy of the battery. The number of batteries in series being charged can be calculated as

$$N \geq 1.05I_{acc} / j \quad (5)$$

where I_{acc} – instantaneous hourly or semi-hourly accidental load, A; j – allowable load during accidental discharge, A/N; 1.05 is a coefficient of reserve. Figure 2 below shows the discharge rate for a battery with respect to temperature rise. A rise in the temperature of the electrolyte of a battery is an indicator that the battery is no longer in good condition. The discharge rate is faster in the first half hour of the battery, evident from the slope of the line labelled (1) in figure 2.

The power rating of a booster charger is calculated as

$$P_{bc} = (0.15N + I_n)*2.35n \quad (6)$$

where I_n = constant load current. The charge current I_c is calculated as

$$I_c = 5N + I_n \quad (7)$$

Table 1 shows the influence of the strength of charge current on charge duration. The lower the ampere-hour rating of the battery, the faster it charges. In the so called battery firing, higher currents are used to charge the battery in order to reduce the number of charging hours.

II. Models of Battery Charging Circuits

The battery charger of Fig. 3 is designed using tap changing transformer to ensure that charging voltage is chosen for any rated voltage of the battery to be charged. However the default voltage rating for the battery charging device being discussed here is 12 Volts. At a voltage less than 14.5 Volts, there will be no output from the zener diode D5. Consequently, there will be no voltage on the winding of the overcharge relay because the transistors Q_1 and Q_2 are in their non conducting mode [2], [6].

The primary winding of the transformer T_1 is connected to the system through the contact of the relay K1.1 and the second contact of the same relay shunts the resistor R_3 through the contact $K_{1.2}$. When the battery charges to 14.5 Volts, D5 begins to conduct, leading to the biasing of the transistors Q_1 and Q_2 and the eventual switching of the relay. Then the input voltage of T_1 is cut off and the shunt resistor R_3 is released. This leads to increase in the break over voltage of D5, which continues to conduct even when the battery voltage is less than 14.5. In this condition, charging stops and a process of slow discharge of the battery commences. Meanwhile the battery continues to feed the relay as D5 continues to conduct. At about 13 Volts, the relay goes off and charging resumes.

The response test of the device can be conducted in the laboratory. To do this, the device is disconnected from electricity and a rectified dc voltage is connected in place of the battery to set the response voltage of D5 with respect to voltage variation. Other dc source voltage values can be used but with a voltage range of (14-16) volts to accommodate maximum voltage variation. With the help of the variable resistor, the break over voltage of D5 can be fine tuned while the minimum voltage at which D5 will not conduct is set with R_3.

Table I: Dependent of charge time on charging current

Charge time, Hour(s)	10	8	7	5	3.5	2	1
Charge Current, A	20	21	22	25	30	35	40
Ampere-hour rating, AH	200	168	154	125	105	70	40

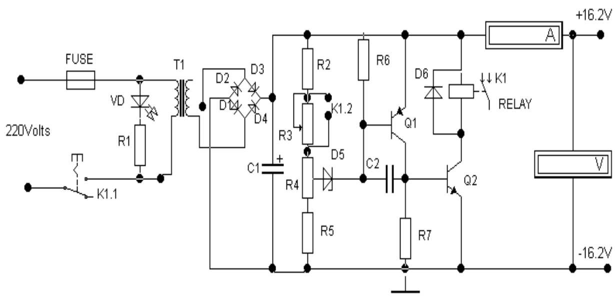

Fig.3. Battery charger with tap-changing transformer

The diagram of Fig. 4 (a and b) is a battery charging device designed for optimum protection of the battery being charged. Relay 1 protects it from receiving voltage lower than the rated charging voltage. The voltage sensor is a light activated transistor Q_3 [7] which triggers relay 1 when light from D_7 falls on it and consequently disconnects the battery at the point marked A on the circuit. Relay 2 also switches the battery off when the charging voltage exceeds the rated value. The sensor is a zener diode VD2 which begins to conduct when voltage from the source exceeds the rated value. When the charging voltage reaches the break-over value of VD2, it begins to conduct and the light emitting diode D9 also begins to conduct. This sends signal to the light activated transistor which, begins to conduct to trigger relay 2 whose contact is at point A Fig. 4(b). Thus D_7 - Q_3 and D_9 - Q_5 form opto-coupling devices [8], [9]. Relay 3 protects the battery from short circuit when the battery terminals are accidentally reversed. Relay 3 is connected at point A and its normally open terminal is connected to a buzzer at point C, into pin 5 of the voltage controlled 555 timer sound generator Fig. 4(b) [10]. The voltage going into the 555 timer at point C comes from the 9 Volts d.c. circuit of Fig. 4(a). The fuse incorporated in the circuit serves to protect the battery in a situation where relay 3 fails to work. If such a scenario takes place, the flow of current from the battery will be completed by R_{21} of Fig. 4(b) thereby increasing the thermal effect on the fuse which eventually leads to its cutting. The charge voltage is regulated by the zener diode VD6. This supplies the biasing voltage to the base of the transistor Q_6 which in turn biases Q_8 - the power transistor that supplies the charging voltage to the battery. As the battery voltage increases, R_{16} conducts more until the voltage at Q_6 becomes insufficient to bias Q_8. Simultaneously, the biasing voltage of Q_7 increases and it begins to conduct, thus grounding the circuit through R_{15} while Q_6 is closed.
The reverse of the above case takes place when the battery voltage drops to a certain level determined by R_{16}. Therefore, Q_6 and Q_7 are responsible for the charge control [11]. The user can monitor the level of the battery voltage the light emitting diodes D_{11}-D_{13} as may be defined by the values of R_{17}-R_{19}.

The diagram of Fig. 5 is a half wave and thyristor powered battery charging circuit [12]. When the voltage transformer is connected to 220 Volts a.c. power line, the rated secondary output voltage reaches the 12 Volts battery through the thyristor SCR1 which gate is fed from two voltage divider resistors R_4 and R_7. SCR1 conducts to charge the battery. When the battery charges to a level determined by R_3 the variable resistor R_4, the zener diode gains its break over voltage and begins to conduct. As a result of this, the thyristor SCR2 opens to ground the source voltage through the variable resistor R_5, R_6 and SCR2. The response voltage of the zener diode is determined by the variable resistor R_5. The capacitor filters all a.c. components from the regulating circuit and R_6 prevents faulty voltage from entering into SCR2. At full charge of the battery, when SCR2 must have grounded the circuit, SCR1 stops conducting. Then the only source of voltage becomes the parallel circuit of SCR1 which is made up of D_3, R_1 and the choke R_2. This voltage will maintain a certain level of the battery voltage to compensate the unavoidable discharge caused by grounding R_3 and R_5. The maximum voltage at which the zener diode will conduct is set with R_5 while the minimum voltage at which the zener will not conduct is set with R_6.

III. ANALYSIS

The analysis of the three presented charging circuits will be based on the following considerations, namely: maximum power transfer, battery protection ability, interactiveness or manoeuvrability and duration of on-line inclusion of the battery on the active circuit. Figure 3 uses relay to isolate the source voltage on the primary side when the battery is fully charged. When this happens, the entire circuit begins to feed from the battery. This makes the fully charged battery not to retain its threshold voltage for a long time. The rate of power consumption now depends on the relay resistance and the series resistance of R_2 - R_5. The circuit is less interactive, though the ammeter and the voltmeter are there and the primary voltage indicator lamp. The minimum voltage at which the relay will not conduct is about 13 volts and the circuit re-switching interval depends on the discharge rate from 14.5V to about 13V. Another disadvantage of this circuit is that when power is switched off from the primary winding of the transformer at the contact K1, the charged battery remains in parallel with the 200 μf polarized capacitor C_1 (0.1 μf capacitor is recommended) for idle battery [2]. This coupled with the high current consumption of the charge circuit helps to discharge the battery faster, but the overall transfer coefficient is nearly 100 per cent observed from the series ammeter included in the circuit. However, if any of the diodes D_1 – D_4 goes bad, the battery will discharge completely. Despite the above mentioned inadequacies, the circuit still has the advantage of manual tap changing capability.

The circuit of figure 5 is a direct on-line thyristor controlled charging circuit devoid of the usual relaying system of protection and control. The series resistors R_1 and R_2 help to increase the overall voltage transfer to the battery and reduce incident heating of the thyristor SCR1, while R_3 and R_5 supply the control voltage. During the charging process, SCR2 is not conducting because of the absence of voltage on its gate. The output voltage from the secondary winding of the transformer is that of half wave. It will supply impulse dc voltage only on the positive half cycle [13], [14]. This is the major reason why no capacitor was attached across the output terminals; else it would have remained a parallel circuit with the battery thereby slowing down the rate of charge. If D_4 is allowed to operate in the circuit as shown in Fig. 5, then when the zener diode begins to conduct, it will ground the positive terminal through SCR1 and the resistors R_3 and R_6. To avoid this, SCR1 should not conduct when SCR2 is conducting. So D_4 will be replaced with a zener diode VD, which must cease conduction when SCR2 is open. The compactness of the circuit is unquestionable but it generates a lot of heat even at normal regime, reason for the use of a choke in the circuit. At full charge, when VD is conducting, the entire circuit becomes grounded through R_4, R_7 and SCR2. This is unacceptable. From the diagram, it is seen that the battery being charged is always in Parallel with R_3 and the variable resistor R_5 which is equivalent to connecting a load of about 0.18 watt across the battery. The disadvantages of the charge circuit is that a good heat sink is needed in SCR2 to withstand the near short circuit method of voltage discharge. Secondly, it cannot handle high ampere-hour battery capacity at a time.

Figures 4(a and b) together make up a charging circuit. The transistor Q_8 supplies the full wave d.c. voltage to the battery to be charged. To increase the output power of the circuit, two or more power transistors can be added in parallel with Q_8 [15]. The complexity of the circuit is as a result of the tripartite protection built into the circuit.

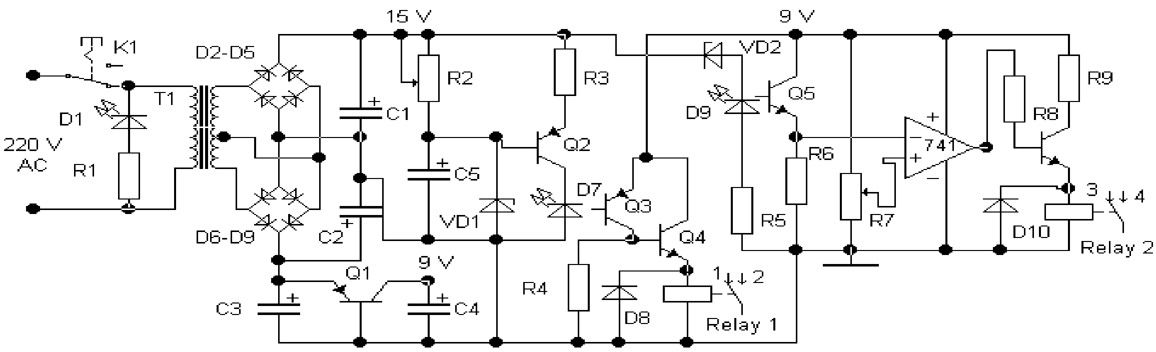

Fig.4 (a) Power supply and protection devices for battery charger

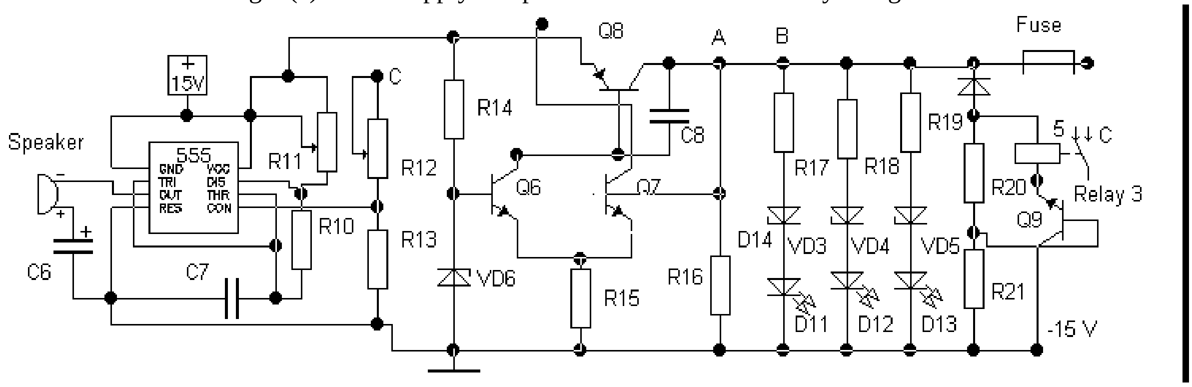

Fig.4 (b) Charge circuit with reversed polarity indicator and alarm

There are two sources of dc supply – one of them is the 15 Volts meant for battery charging, over voltage sensor built with VD2, D_9 and R_5 circuit and the reversed polarity sensor. The other voltage is the 9 Volts used for the protection devices and the buzzer. The choice of components in the circuit makes it unadvisable to use tap changing transformer since the circuit incorporates two powerful capacitors C_1 and C_2. One disadvantage of the circuit is that the voltage level LED indicators may switch off when the battery is fully charged because the zeners VD3 – VD5 will be shunted by the emitter resistor R_{15} through Q_7 and V_{cc}.

IV. Discussion

The newly introduced charge circuit of fig. 4 will perform better than the existing chargers already in use today because of additional technical values attached to it. These include the minimum and maximum voltage protection using relay 1 and relay 2. Relay 3 is used to isolate the charger when the battery is wrongly connected. When the battery is connected wrongly, the buzzer sounds to alert the operator. At full charge, there are two protections against over charge. Firstly, the supply MOSFET Q_8 will stop conducting according to the configuration. If for any reason Q_8 did not cut off during full charge, then relay 2 will handle the situation as the circuit will see it as a condition of over voltage (about 14.5 Volts). Summarily, the charger is fused and equipped with low and high voltage protection, full charge protection and reversed polarity protection.

The circuits of Figures 3 and 5 are some of the common chargers in used today. There are also the direct on-line chargers and the capacitor step down or the transformer powerless chargers. With the inadequacies associated with these models of chargers as shown in Figures 3 and 5 and coupled with their limited power transfer capability, the newly introduced charger tried to cover the lapses associated with these chargers during battery charging process and during storage. The advantages of the new model charger of Fig. 4 greatly out-number the advantages of those chargers mentioned above. The assessment is based on technical data, rate of power transfer, availability of components and comfort of application.

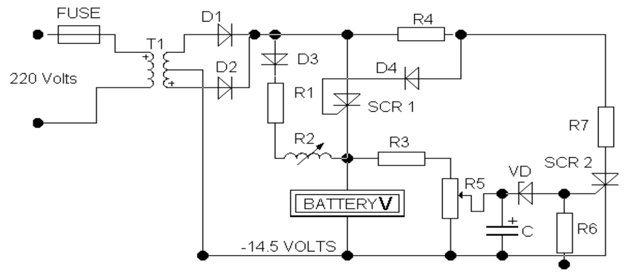

Fig.5. Thyristor fired battery charger

V. Conclusion

The new model of battery charger shown in Fig. 4 (a and b) has better technical advantage over the chargers in use today in terms of charge current output, voltage regulation and battery life protection. The charger is designed to give single tap voltage output with automatic voltage regulated ac input to the charging transformer (not shown) and ensures steady voltage amplitude to the battery terminals. So the issue of battery firing has been technically eliminated. One of the most characteristic properties of the charger is its ability to provide visible isolation of the battery when it is fully charged or whenever there is fault. By this, there will never be any risk of fire. The device is also able to detect and isolate the battery when the charging voltage falls below nominal value and to reconnect the battery to the charger automatically when the charging voltage normalizes.

References

[1] L. D. Rodgkova and V. S. Kozulin. "Electrical equipments of power stations and substations," Moscow Energoatomizdat, 1987 p572-581.

[2] V. A. Nikitin. "Aid to Radio Lovers". M Patriot, 1990 108 Edition pp. 52-54.

[3] John Duffie and William Beckman. Solar Energy Thermal processes. John Willey Inc. 1974.

[4] Ganguli T. K. Probhakar M. V. et al. Transformers. Tata McGraw-Hill Publishing Company Ltd., New Delhi, India, 2005, 2nd edition pp. 138-153.

[5] Datt S.K. "Power electronics and control". Prentice-Hall,Eaglewood Cliffs, USA, pp. 16 – 27 and 96 – 105.

[6] Boylestad R. And Nashelsky L,, "Electronics circuit analysis and design". Prentice Hall Inc. Eaglewood New Jeysey, 1991, 2nd edition.

[7] Up-to-date World transistors-diodes, thyristors and IC's comparison tables. Tech Publications PTE Ltd Singapore, 2001.

[8] Forest M. Mims III. Engineer's Mini-Notebook. Optoelectronic Circuits. A Siliconcepts book, 1986, 2nd ed. pp. 42-48.

[9] D. A. Weamen, "Electronic circuit analysis and design". McGraw-Hill Companies. Inc. Missour, 1996.

[10] Forest M. Mims III. Engineer's Mini-Notebook. 555 Timer Circuits. A Siliconcepts book, 1984, 3rd ed. pp. 15, 27-29.

[11] P. Rufus Turner. "Abc's of Integrated Circuit,". Howard W. Sams and Co., Inc. Indiana USA, 1977, 2nd ed. pp. 8-17.

[12] John Markus. "Sourcebook of Electronic circuits," McGraw-Hill Book Company, New York, USA 1968, pp. 72 – 75.

[13] Journal of Engineering and Applied Sciences. Nnamdi Azikiwe University, Awka, Nigeria Vol. 4 Nos. 1 and 2, 2008. ISSN: 1119-8109, pp. 58.

[14] D.C. Gangoli "Physics Principles with Applications," Prentice-Hall, Eaglewood Cliffs New Jersey, 1991, 3rd edition pp. 546-549.

[15] The TTL Data Book for Design Engineers. Texas Instruments Incorporated USA, 1973, 1st ed. pp. 117-119.

Author's Profile

Dr. Josiah C. Onuegbu

Born in Anambra State Nigeria on 24th February1966. Received his M. Eng. degree in electrical engineering in the field of electric power stations and substations from Kyrghyz Technical University, Bishkek (Frunze) USSR in 1994. Then Ph.D degree in the field of electric machines from Nnamdi Azikiwe University, Awka, Nigeria in 2012. The author's major field of study is electric machine design. He joined Nnamdi Azikiwe University, Awka in 1999 as a lecturer. He has published many journal articles and an engineering novel titled 'why is power erratic?' Awka, Anambra State. Amaka Dreams Ltd 2008. Dr. Onuegbu is a member of five professional bodies including the Nigeria Society of Engineers and COREN. He has worked for many committees of the Department of Electrical Engineering especially as the Chairman of Examination committee. He is also a member of Examination Malpractice Committee of the Faculty of Engineering for many years.
Email: onuegbujo@yahoo.com.

Dr. Emmanuel A. Anazia

Born in Delta State of Nigeria on 10th October 1963. Received his M. Eng. and Ph.D. degree in Electrical Engineering in the field of power system and machines from Nnamdi Azikiwe University Awka, Nigeria in the year 2000 and 2008 respectively. Dr. Anazia is a registered Electrical Engineer with COREN and a member of the Nigeria Society of Engineers has extensive experience in the industry and academia. He is currently a lecturer in power system analysis in the Department of Electrical Engineering, Nnamdi Azikiwe University, Awka, Anambra State of Nigeria. He has worked for many committees of the Department of Electrical Engineering especially as the Chairman of Students Industrial Work Experience for many years. His research interest is in power generation and automation.
Email: aninyemunzele@yahoo.com