American Journal of Engineering Research (AJER)
e-ISSN : 2320-0847 p-ISSN : 2320-0936
Volume-02, Issue-07, pp-185-190
www.ajer.org

Research Paper Open Access

Design of Three Phase Solar-Based 4.5kw Ac Power Inverter Station

Dr.J.C. Onuegbu, Dr.F.O. Enemuoh, Dr. E. A. Anazia
Department of Electrical Engineering Nnamdi Azikiwe University, Awka, Nigeria

Abstract: - The design model of a 4.50Kilowatt, 3-phase, 50 hertz solar-based power generating station was examined by the paper. The power station is a dual source input generating station using 8 series connected 100A, 12V batteries per phase as backup, the solar panels being the main frame. An inverter of 12Volt direct current input voltage was incorporated to supply an output of 3-phase, 220Volts and 50 hertz alternating current. A charging circuit was installed to monitor charging level and to preserve the accumulator's life span. The paper also looked into the solar-based power station component design model. The batteries therein are back-up and the system will ensure 24-hours reliable power supply. The setup has a normally closed switching relay ready to pickup the auxiliary battery supply within a few milliseconds after the solar source voltage drops below a stipulated level. The three phase a.c. voltage was achieved using standby on-line circuit with cascaded 741-based flip-flop at the base of the transistor drivers of the 3-phase power transformer. This model circuit reduced the load on each phase winding and facilitated reliable and uninterruptible power supply. The delta-wye connected transformer will guarantee proper phase shift of 120 degrees that will emulate alternating current voltage similar to the conventional generator voltage.

Keywords: - *Delta-wise connection, Multivibrator, Power MOSFETS, Renewable energy, Sinusoidal signal*

I. INTRODUCTION

Renewable energy has come to compliment the insufficient and epileptic supply of the energy needs of the 21^{st} century. The new found knowledge in Engineering and Technology has made it possible to harness the abundant energy resource of the sun to generate electricity [1]. The paper is on the design of three-input three phase inverter. The presented paper tried to utilize three energy sources, namely: solar panel, lead–acid accumulators and electricity (if available) to provide safe, reliable and efficient source of electricity to an average middle class family. Solar-based electricity power system supplies one of the cleanest sources of energy. It is safe, noiseless and cheap on the long run. The work being presented was based on On-line bypass mode of operation [2]. This means that the solar cell and the mains supply are complimenting each other but the accumulator is constantly fitted at the supply terminal. The relay which feeds the solar panel into the charging circuit is powered separately from a rectified 12 volts dc supply from the mains Fig. 1.0. This makes the solar panel to give way whenever there is availability of electricity.

Three phase design model was applied in this UPS to ease the load on the MOSFETs. The 4500watts total power rating of the system was distributed among the three phases. The design was done in such a way that the damage of any one pulse generator does not result to total blackout. Instead, when any of the three pulse generators goes bad, only two phases will be affected and can be isolated from the system while the remaining two pulses continue to supply one phase voltage that is distributed equally on the three secondary windings. Finally, the manoeuvrability and ease of trouble shooting of the device is guaranteed by the choice of simple and cheap components.

II. DESIGN OF UPS TRANSFORMER

Design data

Input Voltage: V_1 = 12 Volts dc
Output Voltage: V_2 = 220 Volts ac
Operating frequency: f = 50Hz

Stacking factor: $K_w = 0.80$
Current density: $J_1 = 8.1A/mm^2$ or $8.1*10^2 A/cm^2$ (for primary winding)
Current density: $J_2 = 2.7A/mm^2$ or $2.7*10^2 A/cm^2$ (for secondary winding) [3]
Maximum flux density: $B_m = 1.2$ Tesla (assumed)

III. DEFINITION OF MAIN PARAMETERS

Input current: $I_1 = 4500/12 = 375A$ or 125A/phase
Output current: $I_2 = 4500/220 = 20.5A$ or 6.83A/phase
Voltage per turn: $V_t = C\sqrt{S} = 1.0\sqrt{1.5} = 1.22V$
where $C = \sqrt{4.44*f*r*10^3}$ and r - permeance of iron core, $r = \Phi/I_1N_1$ [4]
For shell type transformers: C= (1.0 to 1.2)
The maximum magnetic flux: $\Phi_m = V_t/4.44f = 1.22/4.44*50 = 0.0055$ Weber
Net core section: $A_i = \Phi_m/ B_m = 0.0055/1.2 = 0.0046m^2 = 46cm^2$
Gross core area: $A_g = A_i/ K_w = 46cm^2/0.80 = 57.5\ cm^2$
Diameter of circumscribed circle: $d = \sqrt{A_g/0.5} = \sqrt{57.5/0.5} = 10.72cm$
Lamination thickness: (L_T) = Width of lamination $(W_L) = \sqrt{A_g} = \sqrt{57.5} = 7.6$ cm
The area of window A_w will be defined using the equation that defines the power rating of a three phase transformer.
Power rating of three phase transformer is defined by the expression:
$S = 3.33*f*A_i*B_m* A_w*K_w*J_1$ [5], from where the area of window becomes:
$A_w = S/3.33*f*A_i*B_m*K_w*J_1 = 4500/3.33*50*46*10^{-4}*1.2*0.8*8.1*6 = 0.000756m^2$ or $7.56cm^2$. This will give a window area of: A_w = (4.5cm by 1.68cm).

IV. NUMBER OF TRANSFORMER TURNS

Number of turns of the primary windings $N_1 = V_{in}/V_t = 12/1.22 = 9.64 \approx 10$ turns. Number of turns of the secondary windings $N_2 = V_2/V_t = 220/1.22 = 180.3 \approx 181$ turns.

V. CONDUCTOR CROSS-SECTIONAL AREA

Primary winding conductor: $A_1 = I_1/J_1 = 125/8.1 = 15.43mm^2$. The diameter of the primary winding conductor: $d_1 = \sqrt{4*A_1/\pi} = \sqrt{4*15.43/\pi} = 4.43mm$ (2.5*2mm wire). This will give 20 turns of two parallel wires. The primary winding conductor: $A_2 = I_2/J_2 = 6.83/2.7 = 2.53mm^2$. The diameter of the secondary winding conductor: $d_2 = \sqrt{4*A_2/\pi} = \sqrt{4*2.53/\pi} = 1.80mm$.

VI. POWER SUPPLY CIRCUIT

The major device in the power supply circuit is the battery charger. There are three different voltage inputs to the oscillator. The battery is the default power source and then the solar panel and the mains ac can be selected alternately using a relay RL. This three-input inverter is designed for reliability and comfort aimed at guaranteed 24-hour availability of electricity. As shown in Fig. 1.0, the relay feeds directly from the mains source, where the normally open contact (A) is connected to the rectified voltage and the normally closed contact (B) is connected to the solar panel [6]. The arrangement is such that the UPS will always take source from the battery.

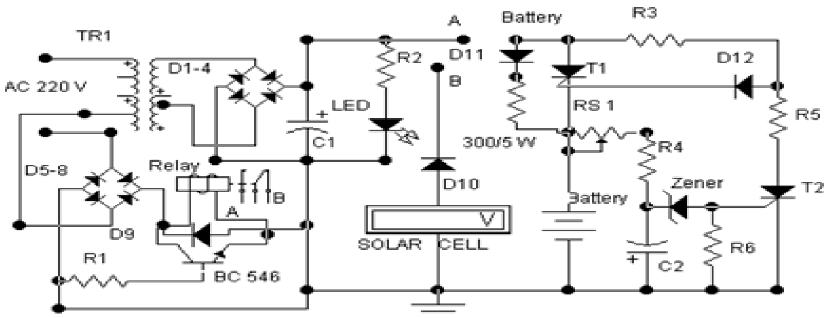

Fig. 1.0 Power supply and Battery charging circuit [7]

When there is no ac, the relay is de-energized and it goes back to the normally closed contact which links the solar panel to the charging circuit. To power the station using accumulators, the number of accumulators required is calculated as shown: $100\text{Amperes-Hour}/I_1 = 100\text{Amperes-Hour}/375A = 0.27$hour or 16 minutes (for one accumulator). To sustain the solar-based power station for 6hours at 4500 watts, an imaginary

2250AH lead-acid accumulator is needed, which is approximately:

2250AH/100A = 22.5 ≈ 23 batteries. If each 100AH battery at 12 volts gives 100*12 = 1200watts-hour, then 23 batteries will give: 1200*23 = 27600watts-hour or 4600watts-6hour. The 23 batteries will be arranged in parallel since only 12 volts is required for the power station inverter [8].

VII. BATTERY CHARGING CIRCUIT

The battery charging circuit contains two thyristors T_1 and T_2. T_1 is biased through the diode D_{12} to conduction to link the positive terminal of the battery to the rectified 15 Volts from the ac supply to start charging. When the battery is charged to a value specified by the variable resistor RS, usually 14.5 Volts [9], the zener diode as shown in Fig. 1 goes into conduction and sends biasing voltage to the gate of the thyristor T_2 which also goes into conduction and grounds the battery through the resistors R_4 and R_6. The resistor R_7 is used to stabilize the break over voltage of the zener diode while the capacitor C_2 is used to prevent zero resistance grounding of the battery through R_5. The voltage at the zener diode is controlled by the discharge time of the capacitor C_2.

VIII. SOLAR PANEL AREA

The area of the solar panel required to power this station can be gotten from assumption using the solar constant (I_{sc} =1353watts/m^2) [10, 11]. For 4500watts, the needed area is 4500/ I_{sc} = 3.326 m^2 ≈ 4.0 m^2 solar panels connected in parallel.

IX. THE MULTIVIBRATOR

The multivibrator is a simple 5-resistor Wien bridge circuit designed on the principle of 741 op-amp with 2 capacitor interface to facilitate the oscillation [12]. Fig. 2.0 shows a sine wave oscillator on the bases of which the inverter was built. C_1 and C_2 define the shape of the output waveform while RS is used to tune the device to oscillation. The numerous MOSFETs involved in the output circuit of the inverter makes it imperative to incorporate driver circuit at the output terminals of the 741 op-amps.

The op-amps were used to generate independent sine-wave frequency that went into the base of the MOSFETs through the driver circuit. To get 3-phase output voltage, the three independent output waveforms were shifted in phase by the use of six diodes to produce 3-phase ac voltage with neutral. As shown in Fig. 4.0**,** the output transformer can be connected in delta for loads that feed on line voltage.

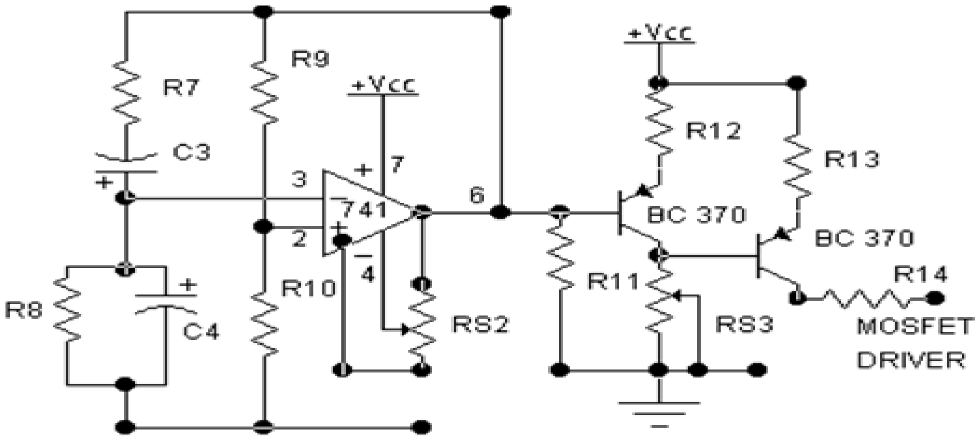

Fig. 2.0 Multivibrator circuit

From fig. 2.0, $V^+ = V^-$, $C_1 = C_2 = C_3$, $R_1 = R_4 = R$; $R_3 = 2R_1$

Where $V^+ = (R_1||C)V_o/(R_1||C)+R_1+ C = R_1*(V_o/ Cs)/(R_1+(1/ Cs))/[R_1*(1/Cs)/R_1+1/Cs+ R_1+1/Cs] =$
$R_1*Vo/(R_1*Cs +1)/[R_1/(R_1*Cs +1)+ 1/Cs + R_1$

And $V^- = R_1*V_o/(R_1 +2R_1) = R_1*V_o/3R_1= V_o/3$

Now, $V^+ = V^-$, ∴ $R_1*V_o/(R_1*Cs +1)/[R_1/(R_1*Cs +1)+ 1/Cs + R_1 = V_o/3$

Therefore, $3R_1/Cs*R_1+1 = (R_1/Cs*R_1+1) +1/Cs+R_1$

$2R_1/1+Cs*R_1 = (1/Cs+R_1) = 1+Cs*R_1/Cs$ or $2Cs*R_1 = (1/Cs+R_1)^2$

$1+2Cs*R_1 + (Cs*R_1)^2$

$0 = 1+C^2s^2R_1^2$; $C^2s^2R_1^2 = -1$; $s^2 = -1/C^2R_1^2$; $s = (-1/C^2R_1^2)^{1/2} = j/R_1*C$. At $s = j\omega$; $f_o= 1/2\pi R_1C = 0.159/RC$, Hz. This is the output signal frequency of the op-amp. The input impedance of 741 op-amp is 2MΩ with output impedance of 75Ω [13].

X. THE POWER MOSFETS

The power MOSFETs used in the power output is IRFZ44 with the following properties: V-mos = 60Volts, 50A, 150 watts. Its equivalent are BUK556-60, 2SK2049 and 2SK 2499 [14]. IRFZ44 MOSFET has higher theoretical output power than the practical output power. Using a push-pull amplifier circuit with an efficiency of about 78% [15], the theoretical output power can be calculated as:

$P_{max} = Vce_{max}I_{op} = 60*2.5 = 150$ watts.

Output power $P_{op} = V_{op}*I_{op}*\eta$,

where efficiency of a push-pull amplifier, $\eta = P_{ac}/P_{dc}$

$P_{ac} = Vcc*Ic_{max}/2$

$P_{dc} = 2Vcc*Ic_{max}/\pi$

$\eta = P_{ac}/P_{dc} = (Vcc*Ic_{max}/2)/(2*Vcc*Ic_{max}/\pi) = \pi/4 = 0.785$

$\therefore$ output power $P_{op} = 220*2.5*0.785 = 431.8$ watts

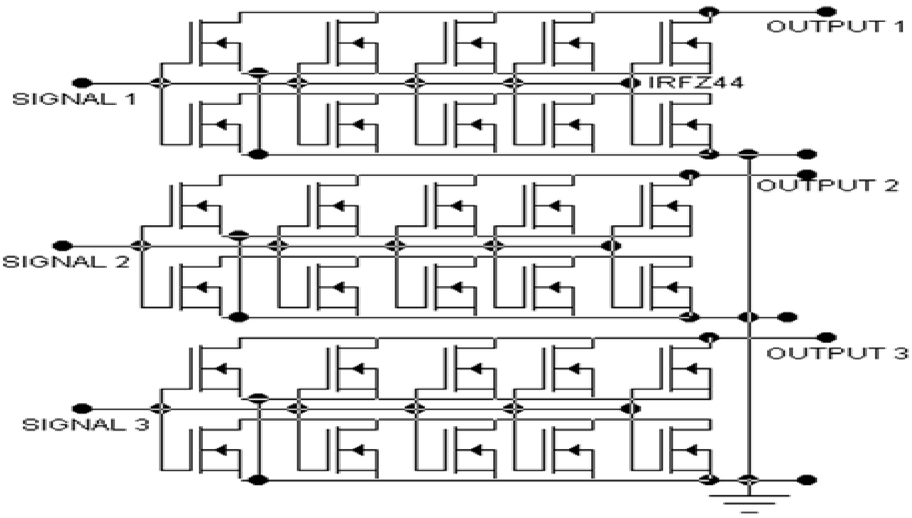

Fig. 3.0 MOSFET arrangement for output voltage transformer

A look at the power rating of the solar-based power station shows that the 4500watts will require 4500/150 =30 pieces of IRFZ44 or 10 pieces of IRFZ44 per phase cascaded as shown in Fig. 3.0.Figure 4(a) shows a Δ/Y connected inverter transformer requiring three input signals with center tapped V_{cc} to give out three phase voltage. Figures 4(b) and 4(c) show wye-wye connection of inverter transformer with phase shift using diodes. The circuit of 4(c) will require 4 sinusoidal signal inputs while the other two circuits of 4(a) and 4(b) will require 3 sinusoidal signal inputs to generate a 3-phase circuit. The output of Fig. 3.0 forms the input of Fig. 4 (a, b and c) arranged as appropriate.

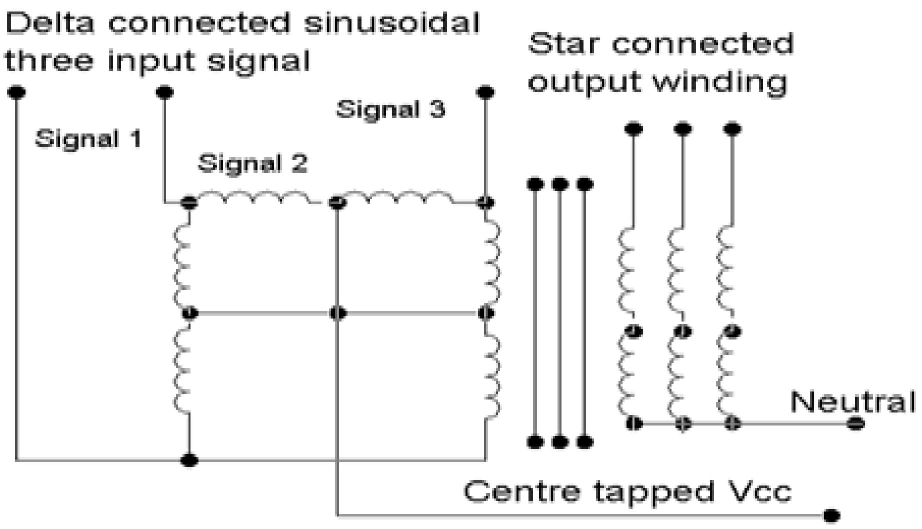

Fig. 4.0(a) 3-phase delta-wye connected transformer without diodes

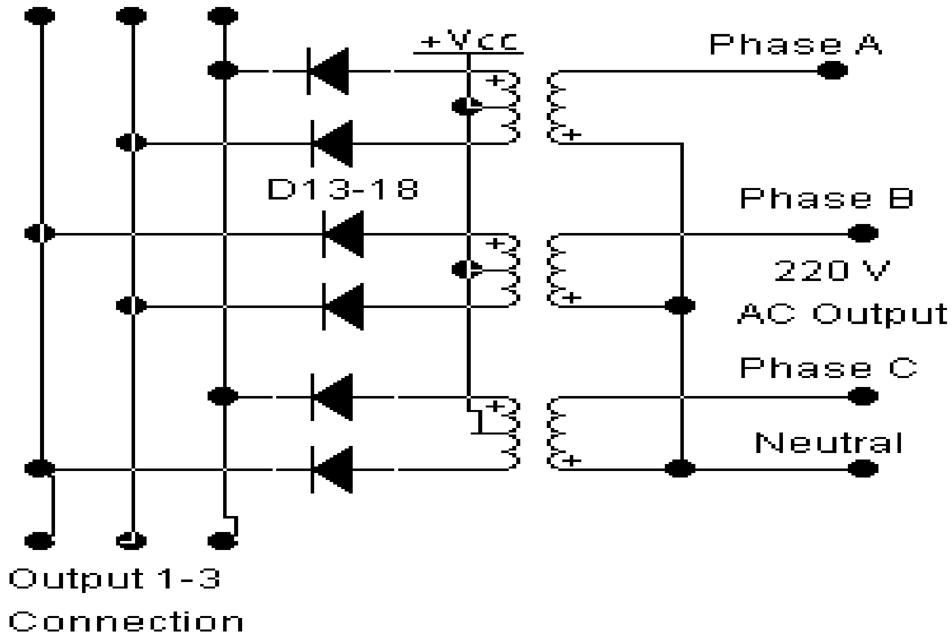

Fig. 4.0(b) 3-phase wye-wye connected transformer with 6 diodes

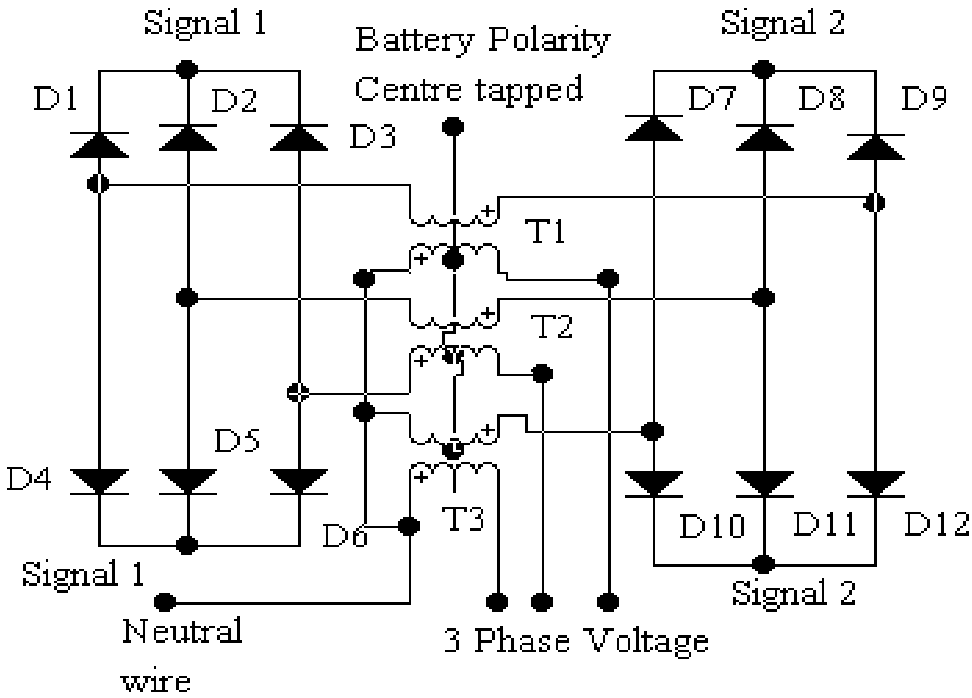

Fig. 4.0(c) 3-phase wye-wye connected transformer with 12 diodes

XI. CONCLUSION

The modeled UPS which was meant to support a load of 4500 watts for 6 hours can be extended to 24 hours service at a load of 1150 watts. The usual high harmonic associated with singles phase systems has been reduced by the use delta-wye connected transformer. Again, mass and weight of inverters have been grossly reduced by the compactness of three phase inverter. The problem of heat removal is obvious and that is the reason for the incorporation of a small dc fan to cool the power MOSFET bank. The number of cascaded MOSFETs will be reduced with the availability of MOSFETs with higher power rating. The economic application of this type of renewable energy resource will be realizable in combination with the introduction of energy saving bulbs.

REFERENCES

[1]. World energy; Looking Ahead to 2020. Report by the Conservation Commission of the World Energy Conference 1978, Mid-County Press London, SW15.

[2]. Onuegbu J. C., Anazia E. A. and Okafor T. C. Comparative analysis of discrete based UPS topologies. Journal of Electrical and Telecommunication System Research. Nnamdi Azikiwe University, Awka. Vol. 3 No. 3, 2009, pp29-36.

[3]. Paul Horowitz and Winfield Hill., The art of Electronics. Cambridge University Press, 1989 pp 284293.

[4]. Pearman P., Electrical Machinery and transformer Technology. Saunders College Publication, 1994, pp 387-444.

[5]. Handbook of PV System Design Practices. Sandia National Laboratories USA, 1973.

[6]. Horowitz S. H. and Shadke A. G., power system Relaying. Research studies Press, 1996, 2nd Edition, pp 7-12.

[7]. John Markus, Sourcebook of Electronic circuits. McGraw-Hill Book Company, USA, 1968, pp75 and 491-496.

[8]. Robert Simon, Solar electricity. A practical guide to designing and installing small photovoltaic systems. Prentice Hall, New York, USA 1977.

[9]. Nikitin V. A., Radio Construction Handbook. M. Patriot, Moscow, 1990, 108th Edition. pp 52-54.

[10]. John A. Duffie and William A. Beckman, Solar Energy Thermal Processes. John Wiley Inc., USA, 1974.

[11]. Handbook of PV System Design Practices. Sandia National Laboratories, USA, 1973.

[12]. Forest M. Mims III., Engineers Mini-notebook. A Siliconcepts ™ Book, USA, 1991 1st Ed. pp 47.

[13]. Up-date World's Transistors-Diodes, Thyristors and IC's Comparison tables A-Z. Tech. Pub. PTE Ltd, Singapore, 2001 Vol. 1, pp 775.

[14]. Kasatkin A. S. and Nemtsov M. V., Electrical Engineering. Mir Publishers Moscow, 1990, 2nd Printing. pp 278-281.

[15]. Nagrat I. J. and Kothanri D. P., Power System Engineering. Tata McGraw Hill Ltd, New Delhi, 2004, pp 25 and 26.