Improving the Performance of A. C. Voltage Stabilizer Using Parallel Cascaded Relays.

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ABSTRACT:
This work entails design, construction, packaging and evaluation of a prototype automatic a.c. voltage stabilizer using parallel cascaded relays. The unit was cascaded to provide more switching contacts on the auto-transformer. The overall system design is a compact assembly encased in a portable metal box with handle which can operate on 90v minimal input voltage. In this paper, a parallel cascaded relay what is essential was implemented in the design of voltage stabilizer damp power system oscillation so that electrical power supplied to appliances remains constant over a range of values. This new approach of parallel cascading the switching relays to provide considerable of voltage was implement and tested. The result obtained from testing with variable a.c. source shows that the voltage stabilizer which was implemented with parallel cascaded relays gives efficiency of 15% increase when compared with our conventional voltage stabilizers.

KEYWORDS: A.C. Stabilizer, cascaded relay, auto-transformer and switching contacts.

1.0 INTRODUCTION

Voltage is the most important parameter in electrical power [1] system and it is necessary to be maintained a constant output voltage because, it is the driving force that pushes current through the conductor. Voltage stability is vital for safety and optimal performance of electrical appliances. Most electrical appliances are designed for optimal operation, maximum length of service and safety if the power rating of the appliance is maintained. It is essential to hold the voltage at the consumers' premises within acceptable unit of magnitude. The bulk of the solution lies on the development of an electronic circuit that monitors the main supply and takes the decision on its own to initiate a switching action that will eventually lead to the load seeing a voltage within acceptable normal range [2]. Fluctuation in power supply can have adverse effects on power equipments [3] such as radio, Television, Fan etc. which ranges from humming heating fire and damage.

Again, wide Voltage deviation from the normal supply can adversely affect equipment like refrigerators, air conditioners, videos, television sets etc. Low voltage could cause the compressors of refrigerators and air conditioners to develop fault and if not switched off could heat up and get burnt [4]. It also causes malfunctioning in electronic appliances like poor reception in radio and video signals. On the other hand, over voltage can cause many instruments to burn out due to insulation breakdown [5].

The ultimate aim of any electrical power supply authority is to provide the required power to the consumers under all load conditions. At generating stations, the automatic voltage regulator (AVR) controls the terminal voltage, but even at that, it is observed that the AVR do not provide adequate terminal voltage responses, for that, the supply voltage continues to dwindle [6]. The classifiable, most cost effective and widely used material consists of installation of Power Supply System (PSS) in addition to automatic voltage regulatory of the generator [7]. Supply authorities find it very difficult to maintain this voltage as a result of bad city planning, unplanned distribution and unbalance in loading. As a result, voltage in most congested urban centers fall as low as 100V and sometimes could rise to 300v. Voltage could rise momentarily when reactive loads are switched on or off the supply network

2.0 METHODOLOGY

The technique adopted in this work was to use parallel cascaded relay in design of voltage stabilizer.

The design comprises of various units starting from transformation unit, through rectifier, filter unit, regulating unit to the comparator which evaluates the available voltage and the reference voltage, then the difference in value triggers up the associated parallel cascaded relays that connects the appropriate auto transformer tapping to produce the output voltage.

The lamination plate was procured and cut to the required shape and dimension on a cutting machine. The number conformed with the calculated result. The sheets were vanished with shellac, packaged and clamped in a vice. The transformer was wound in clockwise direction circumferentially around the core. Output terminals were drawn out after completion of the appropriate number of turns.

2.1 Transformer core construction

The core material used in this work is silicon steel type of 0.5mm thickness per sheet. The limbs and yoke of the transformer were cut to the required length using a cutting machine. The upper and lower parts (the yoke) were drilled in the drilling machine to make provision for clamping. The lamination sheets which were of square section were treated with shellac for purposes of insulation. The sheets were arranged alternately and stacked. The assembled sheets were clamped in the vice for two days to dry.

Winding Arrangement: The conductor materials were wound round the core in a clockwise direction starting from the lowest voltage, tapings were drawn out after the number of turns have been completed. The winding technique employed is the helical method which is done concentrically around the core.

2.2 Description of the System Unit

The different sub-units of the system are:

(1) The transformer section.
(2) The rectifier and filter circuit
(3) The regulating and comparator circuit.
(4) The switching device.

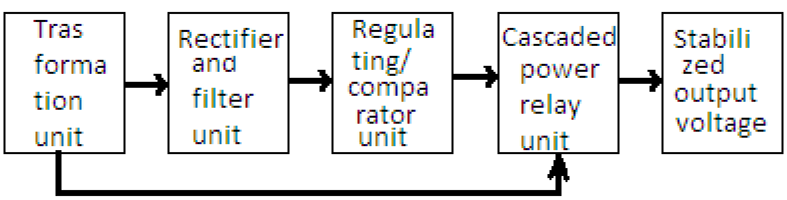


Fig. 1. Block diagram of cascaded relay stabilizer.

The transformation unit consists of a power transformer (specifically an auto-transformer in this case) with multi-tapped secondary winding for provision of power to the control circuit and the appliances requiring stable supply.

The rectifier and filter circuit is responsible for rectifying and smoothing the alternating voltage from the transformer to provide a ripple-free d.c. voltage used to energize the regulating/comparator circuit.

The regulating and comparator unit is responsible for comparing the output voltage with desired/reference to drive a signal that triggers the switching circuit to function appropriately. This unit detects deviation from predetermined range of input voltage with zener diodes as regulators and transistors as comparator. The voltage level detector employs switching transition connectivity using common emitter mode of connection and drives a signal that activates the switching components to function appropriately thereby maintaining a steady output.

The cascaded power relay (CPR) is responsible for the switching process which completes the stabilization. This switching requirement was achieved by the use of five parallel cascaded power relays. The relay contacts were used to switch the auto-transformer tapings and change the voltage/turn ratio of the transformer.

NPN transistor in common emitter configuration operation on the saturation and cut-off region, which acts like an amplifier that amplifies small voltage level to a sufficient value is enough to power the relays, resulting in a clock pulse above 7v applied between the base and emitter which provides the switching mechanism.

Protective device like fuse is incorporated in the system to check the ugly consequences of voltage. There is power ON and OFF switch and a fuse for the normal voltage protection switch and 30 – 300 a.c. voltmeters with light emitting diode for power indicator.

2.0 DESIGN OF THE TRANSFORMER

The emf

$$E = \frac{Md1}{dt} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

By Faraday's law of electromagnetic induction.
Where M is mutual inductance.

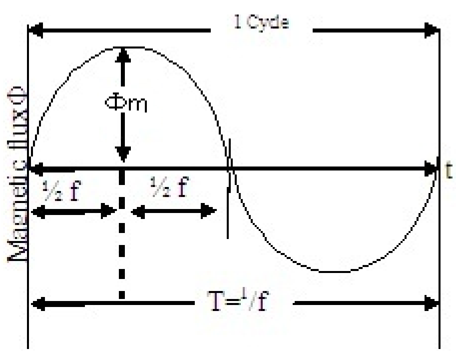


Fig. 2. Sinusoidal flux variation.

As shown in the figure above, flux increases from zero to maximum value (Φ_m) in a quarter of a cycle (1/4f), so average rate of change of flux

$$= \frac{\Phi M}{1/4f} = \frac{\Phi M}{1} \div 1/4f \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

$$= \frac{\Phi M}{1} \times \frac{4f}{1} = \quad 4f\Phi M\ wb/s \quad \dots\dots\dots\dots\dots\dots\dots\dots (3)$$

Average emf per turn = 4fΦM volts …………………..(4)

For a sinusoidal flux variation, rms value of induced emf,

E = 1.11 x average value ………………………..(5)

Rms value of emf per turn = 1.11 x 4fΦM volts = 4.44fΦM …………… (6)

Induced emf in primary winding is given as E_1 = (induced emf per turn x no. of primary turns) $4.44f\Phi MN_1 = 4.44N_1B m A$ ………………………. (7)

A Similarly the rms value of emf induced is secondary winding $E_2 = 4.44f\Phi MN_2$ = $4.44fB_MAN_2$ ……………………………………… (8)

It is seen that $E_1/N_1 = E_2/N_2 = 4.44f\Phi M$ which implies that emf per turn is the same in both windings. In an ideal transformer under no – load condition, $V_1 = E_1$ and $V_2 = E_2$

3.1 TRANSFORMER DESIGN SPECIFICATIONS

Power rating: 2kvA

Input voltage: 90 – 280v
Output voltage: 240V ±1%
Frequency: 50 cycle/sec.
Type: Single phase core type
Cooling scheme: air cooled
Core cross – section: square

(i) Current density – ranges from 2 – 3A/mm^2 for continuously operated power devices.
(ii) Maximum flux density Bm spans from 1.5 to 1.7 tesla (wb/m^2) for power transformer using cold-rolled steel laminations.
(iii) Weighting factor K ranges from 0.75 – 0.85 for single phase core type transformer.
(iv) Stacking factor 0.96-0.97 for cold rolled laminations.
(v) Window space factor KW is taken as 0.33

In the design, the values taken were: S = 2.5A/m^2, Bm = 1.6 wb/m^2, K = 0.80 stacking factor = 0.96, Kw 0.33, Centre to centre distance between limbs is twice the width of the core.

3.2 MAGNETIC CIRCUIT (CORE) DESIGN

(i) Voltage per turn Vt

The output equation of a transformer is given as $S = E.I \times 10^{-3}$ (KVA) ………(9)

But $E = 4.44\, f\Phi M\, N$ and $I = \Phi M/\gamma N$……………………………………………(10)

Therefore $S = 4.44\, f\Phi MN \times \frac{\Phi M}{yN} \times 10^{-3}$ ………………………………………..(11)

$= \frac{4.44 N f \Phi M^2 \, x\, 10^{-3}}{yN}$ ……………………………………………….(12)

$= \frac{4.44 N f \Phi M^2 \, x\, 10^{-3}}{yN}$ ……………………………………………………...(13).

$\Phi^2 M = \frac{s.yx10^3}{4.44f}$ …………………………………(14)

$\Phi_M = \sqrt{S} \quad x \quad \sqrt{\frac{\gamma x\, 10^3}{4.44f}}$ ……………………………………(15)

But voltage per turn Vt = E/N = 4.44fΦ

Substituting the value ofΦM in equation 15 into equation 16

$Vt = 4.44f \sqrt{\frac{Y\, x\, 10^3}{4.44}} \quad x \quad \sqrt{S}$ ……………………………………(16)

$= \sqrt{4.44 f S \, x\, 10^3} \quad x \quad \sqrt{S}$ …………………………………………(17)

$=K\sqrt{S}$ …………………………………………..(18)

Where K = 4.44f γ x 10^3 , f is supply frequency in Hentz, S is electric rating of machine in KVA, Φ_M is maximum flux circulating in the core in webers, γ is the ratio of magnetic loading to electric loading (a constant), E is the impressed voltage in volts, I is the current in amperes and K is weighting factor.

Calculating Vt yields.

$Vt = 0.80\sqrt{1.5} = 0.979796 \cong 0.98$ volts ……………………(19)
To calculate
(ii) Cross – sectional area of core Ai
The Emf equation is E = 4.44FNΦM …………………………(20)
$Vt = 4.44f\Phi_M = 4.44FB_MAi$ ………………………………..(21)
0.98 = 4.44 x 50 x Ai = 355.2Ai …………………………..(22)
$Ai = \frac{0.98}{355.2} = 0.002759009m^2s$ .. …………………….(23)
$= 2759.0mm^2$
(iii) To calculate the diameter of core cross– section (circumscribing circle)
Stacking factor = $\frac{Net\ core\ area\ A_i}{cross\ core\ area\ A_g}$ …………………………(24)
$0.96 = \frac{2759.0}{A_g}$ ……………………….(25)

$2759.0 = 0.96\,(0.50d^2)$
$d^2 = \frac{2759.0}{0.96\ x\ 0.5} = 5747.92$

$d = \sqrt{5747} = 75.8150 \cong 75.8mm$
(iv) To calculate Net window area A_w
The output equation for a single phase transformer is
$= S2.22fB_mAi\ K_w\ A_w\sigma \ x\ 10^{-3}$ …………………………(26)
Substituting values yield
$2.0 = 2.22\ x\ 50\ x\ 1.6\ x\ 10^{-6}\ x\ 2759\ x\ 0.33\ x\ A_W\ x\ 2.5x10^{-3}$
$2.0\ x\ 10^9 = 404248.68\ A_w$
$A_w = \frac{2.0\ x\ 10^9}{404248.68} = 49 = 49mm^2$

3.5 ELECTRIC CIRCUIT (WINDING) DESIGN
(i) Number of turns of primary winding Nρ:
The expression for voltage per turn is given as; $V_t = E/N$
Where N is number of turns and E is induced voltage.
Therefore Nρ = E/Vt…………………………………..(27)
E is 240 for primary circuit $N\rho = \frac{240}{0.98}$
244.897 = 245turns
(ii) Number of turns of secondary winding (tapings) Ns
The secondary windings consist of many tapings, each outputting voltages but within the range of 240v ±1%.
$NS_{min} = \frac{237.6}{0.98} = 242.448 \cong 243$ turns

$NS_{max}\ \frac{242.4}{0.98} = 247.346 \cong 247$ turns

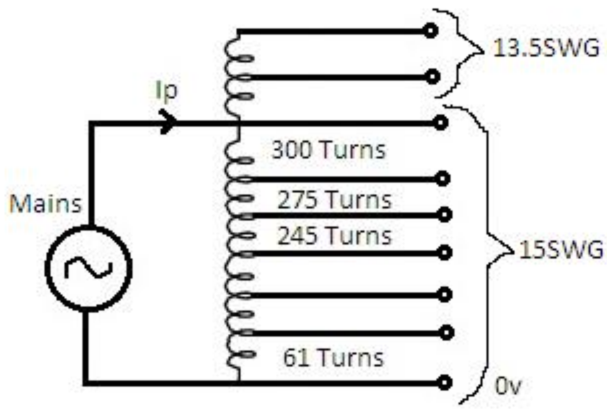


Fig. 3. Single phase auto-transformer.

For the maximum controlled input voltage of 280V the voltage per turn becomes $\frac{280}{245} = 1.143V$

The permissible maximum voltage is 242.4v so the secondary turn becomes $\frac{90}{245}$ = 212turns. At the minimum controlled inflow voltage of 90V > $\frac{90}{245}$ = 0.3674.

The permissible minimum voltage is 237.6v, so the secondary turn becomes $\frac{237.6}{0.3674}$ = 647 turns

The standard wire gauge selected for the common winding of the auto-transformer is 15 SWG while the step – up is 13.5 SWG.

This is to withstand the expected higher current.

(iii) Current requirements

Primary winding current is obtained from the relation P = VI

Therefore I = P/v $= \frac{2000}{240} = 8.33A$

Secondary winding current is obtained from

$1_1N_1 = 1_2N_2$

$1_2 = \frac{I_1N_1}{N_2} = \frac{245\ X\ 8.33}{647}$

$= 3.15A$

(iv) Determination of conductor sizes current density $\delta = \frac{I}{a}$ = 2.5A/mm^2 which implies that a = $\frac{I}{a} = \frac{\pi d^2}{4}$

$d = \sqrt{\frac{4}{11} \cdot \frac{I}{\delta}} = \sqrt{\frac{4\ .\ a}{\pi}}$

Where a is the Cross sectional area and d diameter, for primary:

$d = \sqrt{\frac{4}{3.142}}\ x\ \frac{8.33}{2.5} = 2.12mm$

This gives 13.5 SWG from winding wire conversion chart.

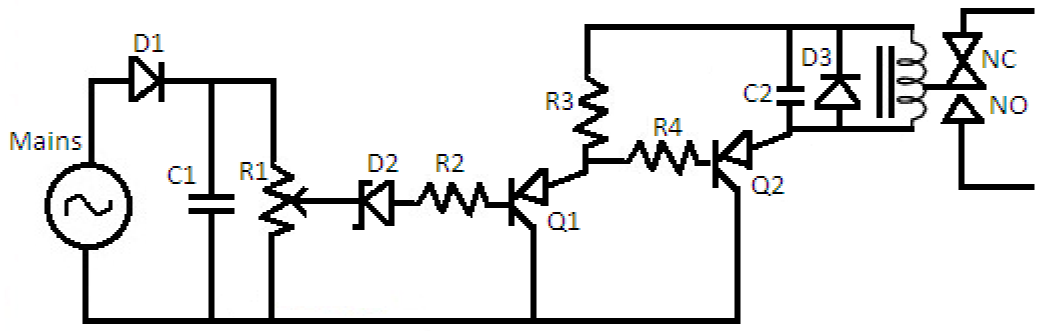


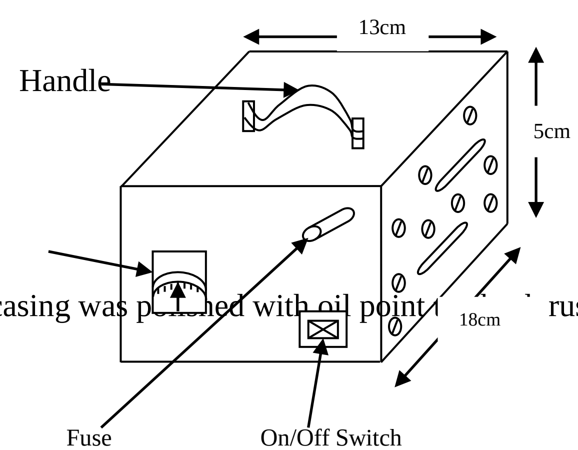
Fig. Schematic Diagram of the control.

3.6 CONTROL CIRCUIT DESIGN

17v rms from the main is used to power the control circuit after rectification by the diode D_1 and smoothened by the capacitor C_1 through the potentiometer R_1 and zener diode D_2 to the transistor first stage Q_1 and Q_2 and second stage to the first relay. While the five relays are then cascaded in parallel to pick the appropriate auto-transformer tapings.

Packaging

A mild steel of 1mm thick was used in constructing the casing. The flate was forged, drilled for air cooling of the transformer and confled into a shape of cuboids 18 x 13 x 5cm dimension. The transformer was mounted on the ease, confled with the entire circuitry and enclosed in the metal cabinet. Other accessories on the casing are the power card, power switch, a.c. voltmeter for output voltage, power indicator (LED), protective fuse, socket outlet and the handle.



The casing was polished with oil point [illegible] rusting.

Fig. The packaged

PERFORMANCE EVALUATION

Since the design was implemented on a modular basis, the different sub units were tested individually such as the transformation unit, rectifier and smoothing unit, the regulator and comparator as well as switching device. The different units were integrated into a single unit and the major test carried out.

The stabilizer was fed from a variable a.c. power supply device (VARIAC) which has an output voltage range of 0-300v a.c.

A digital voltmeter was used to monitor the output readings of the stabilizer and recorded as below:

Table 1: Response to variable Ac power supply

Input voltage	System Response unstable	Output Voltage	Cascaded Stabilizer
90v	Switching device activated	2.20	237.6
150	Switching device activated	2.28	238.9
200	Switching device activated	2.34	239.1
240	No action, direct passage	24	240
260	Switching device activated	243	241.2
270	Switching device activated	246	241.8
280v	Switching deice activated	248	242.4
Above 280	System protection activated	eratic	0

The graphical representation of the test result is as shown below

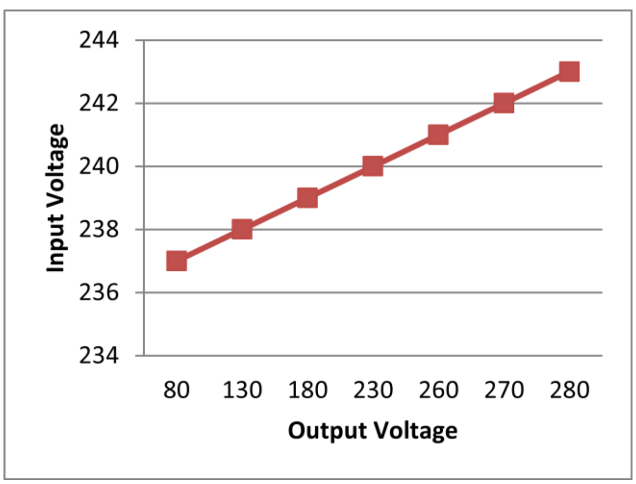
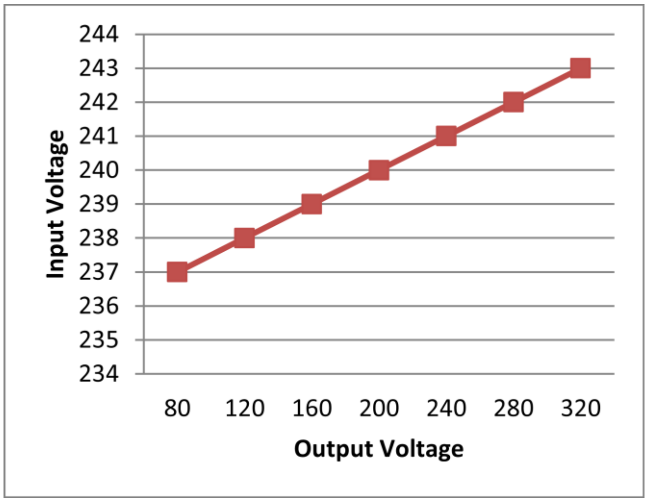


Fig. 2: Graphical Response to Variable



3.0 CONCLUSION AND
4.0 RECOMMENDATION

Test outcome shows that the output voltage remains virtually constant at varying input voltage. However, at extremely low voltages below 90v there was no output voltage because the switching device is not even activated. On the other hand, at voltages beyond 280v the system protection is activated and no output voltage.

Therefore the parallel cascaded relay has made it possible for the device to operate from as low as 90v. The primary objective of this work which was to – improve the performance of conventional a.c. voltage stabilizer was achieved.

The work was designed in consideration with some factors such as economy, availability of components, efficiency, compatibility, portability and durability.

4.1 RECOMMENDATION

The minimum input voltage of 90v is adequate for domestic use in tropics but lower input voltages can still be employed and improved upon by connecting more relays and more secondary turns of the auto-transformer.

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