Design of a Microcontroller Based Automatic Voltage Stabilizer with Toroidal Transformer

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Abstract- Every electrical and electronic appliance is designed to work perfectly at a certain input voltage. In Myanmar, household electrical and electronic appliances are designed to work properly at 220VAC, 50Hz and most of the times the voltage supplied from distribution companies are as low as 130VAC making this appliances to work under threat of low voltage supply. This low supply voltage causes these appliances to malfunction and in most cases damage them. Since the electric power supply/distribution companies are unable to provide the consistent adequate voltage level (220VAC) demanded by these sensitive appliances, therefore there is need for consumers to protect the appliances from damage and ensure their safe operation, hence the use of automatic voltage stabilizers to improve the situation. In this research work, a PIC16F877A microcontroller was programmed to monitor the input voltage from distribution companies and if voltage level is between 130 VAC and 250VAC, it gives a constant output voltage of nearly 220VAC required by the appliance. The model parameter calculated from the design information.

***Keywords* –** Myanmar, Household Electrical, Stabilizer, Input And Output Voltage, Electric Power Supply, Distribution, Microcontroller.

I. INTRODUCTION

The development of any country is largely hinged on the availability of undisturbed and regulated power supply. In Myanmar, electricity is generated by turbine driven synchronous generators at 50Hz at a standard minimum voltage of 11kV. The generated voltage is then stepped up to the primary or secondary Grid voltage of 132kV to reduce power losses during transmission. The generated power then travels from the generating stations to the point of utilization via high voltage Transmission lines, most of which are suspended overhead. However due to the uneven power demand at the load end and the complexity of the consumer network, a third party is required to ensure that the generated electricity is properly distributed according to the load demand, while taking into consideration the necessary geographic and economic factors as they affect the overall socio-economic growth of the nation. In Distribution, electrical power is stepped down at distribution sub-stations of various levels to a final voltage of 400 V (phase to phase) and 230V (phase to neutral) which is directly consumed by most electrical load. 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.

The automatic voltage stabilizer presented in this research aim at designing a suitable Automatic Voltage Stabilizer rated 15 kVA with output 220 VAC, when the input voltage is varying between 130 VAC and 250 VAC.

II. MATHEMATICAL EQUATIONS OF TOROIDAL TRANSFORMER

The rating of the servo motor automatic voltage stabilizer is mainly depended on the transformer rating. The circuit diagram of the servo motor automatic voltage stabilizer including variable autotransformer. The simplest device for regulating the voltage applied to a load is the variable auto-transformer. One of the best known types is the “Variac”. The core consists of a deep stack of ring-shaped laminations. The insulation is removed from a circular track around the upper horizontal face of the winding and a carbon brush carried on a rotating arm makes contact with any desired turn on the winding. For the input fluctuation –40%, +10% toroidal transformer must be withstand the variation of the maximum input voltage is 242 V ≈ 250 V and the minimum input voltage is 132 V ≈ 130 V. The output voltage must be nearly 220 V. Variable transformer type of this AVS is toroidal transformer. The capacity of automatic voltage stabilizer is 15 kVA (single-phase). The output voltage regulation is ±5%.

A. Design Equation

Equations such as e.m.f. equation, e.m.f. per turn in terms of output and output equation are needed to design of the magnetic circuit (main dimensions of core, yoke and window).

B. E.M.F. Equation

When the alternating voltage is applied across the primary of the transformer, it takes a magnetizing current and a flux; φ is established in the transformer core. The flux, φ is uniformly distributed over the transformer core section and is linked with all the turns of primary and secondary windings. The main flux, φ established in the core is alternating in nature.

Hence an e.m.f. is induced in the primary winding, due to the change of main flux, which is given by,

$$e_1 = -N_1 \quad (1)$$

$$\varphi = \varphi_m \cos\omega t \quad (2)$$

$$e_1 = \frac{-N_1 d(\varphi_m \cos\omega t)}{dt} = N_1 \omega \varphi_m \sin \omega t$$

$$E_1 = 4.44 f N_1 \varphi_m \text{ volts} \quad (3)$$

$$E_1 = 4.44 f N_1 B_m A_i \text{ (where } \varphi_m = B_m A_i) \quad (4)$$

Induced e.m.f. in secondary winding,

$$E_2 = 4.44 f N_2 B_m A_i \text{ volts} \quad (5)$$

e.m.f. per turn,

$$E_t = 4.44 f B_m A_i \quad (6)$$

For E.M.F per Turn,

$$E_t = 4.44 f \varphi_m \quad (7)$$

K.V.A rating per phase,

$$E_t = V \times I \times 10^{-3} = \frac{V}{N} \times IN \times 10^{-3}$$

$$= E_t \times IN \times 10^{-3} \quad (8)$$

The ratio of cross-sectional area of the core and the copper area of the windings will be constant for a particular transformer i.e.

$$\frac{A_i}{A_c} = \text{constant} \quad (9)$$

Cross sectional area of core,

$$A_i = \frac{\varphi_m}{B_m} \text{ or} \quad (10)$$

$$A_i = \frac{\sqrt{P}}{5.58} \text{ sq in} \quad (11)$$

Copper area of the windings,

$$A_c = a N = \frac{I}{\delta} \times N$$

$$\frac{A_i}{A_c} = \frac{\varphi_m}{IN} \times \frac{\delta}{B_m}$$

As current density, δ and flux density, B_m is nearly constant,

$$\frac{\varphi_m}{IN} = \text{constant} = r \quad (12)$$

Substituting for IN from Equation 12 into Equation 8,

$$\frac{kVA}{phase} = E_t \times \frac{\varphi_m}{r} \times 10^{-3} \text{ (or)}$$

$$\varphi_m = \frac{\left(\frac{kVA}{phase}\right) \times r}{E_t} \times 10^3 \quad (13)$$

Substituting for φ_m from Equation 13 into Equation 7,

$$E_t = 4.44 f \times \frac{\left(\frac{kVA}{phase}\right) \times r}{E_t} \times 10^3$$

$$E_t^2 = (4.44 f r \times 10^3) \times \frac{kVA}{phase}$$

e.m.f. per turn,

$$E_t = \frac{4.44 B_m N_e f A_i}{10^8} \text{ volt} \quad (14)$$

$$E_t = K \sqrt{(kVA/phase)}$$

$$\text{Where } K = \sqrt{4.44 f r \times 10^3} \quad (15)$$

In order to utilize equation 12, for finding out the e.m.f. per turn, the value of the factor, K is needed. And then, the turns per volt will be got.

$$\text{Turns per volt, } N_e = \frac{E_t \times 10^8}{4.44 B_m f A_i} \quad (16)$$

C. Factor K

Factor, K which basically depends upon the ratio of cross sectional area of core to the copper section of the windings, will be different for two types of transformers i.e. core and shell. The value of factor K with respect to transformer type is shown in Table I.

TABLE I. CONSTANT K WITH RESPECT TO TRANSFORMER TYPE

Type	K (Factor)
(1) Single phase core	0.75-0.8
(2) Single phase shell	1.0-1.1
(3) Three phase core (power)	0.6-0.65
(4) Three phase core (distribution)	0.45-0.5
(5) Three phase shell	1.2-1.3

D. Stacking Factor

To get the required core section, the transformer core is prepared by stacking together thin sheets of laminations. These laminations are insulated on both sides usually by spray of varnish. That, the assembled core includes the area of insulation as well. The gross core section A_{gi}, is related with the net core section, A_i, by a factor K_s called stacking factor.

$$\text{Thus, } A_i = K_s A_{gi} \quad (17)$$

K_s = stacking factor, usually value is 0.85 ~ 0.9.

E. Flux Density (B_m)

The voltage equation as well as output equation indicates that the higher value of flux density B_m is chosen, the core area Ai reduces. This will reduce the diameter of circumcircle thereby reducing the length of mean turn. The choice of B_m will also depends upon the type, service conditions of the transformer. It has already been pointed out that a distribution transformer should be designed for lower iron losses giving good all-day efficiency. Therefore, for distribution transformer comparatively lower flux density is assumed.

Using hot rolled silicon steel

Power transformers - 1.2 to 1.4 Tesla

Distribution transformers - 1.1 to 1.3 Tesla

Using cold rolled grain oriented silicon steel

Power transformers - 1.5 to 1.7 Tesla

Distribution transformers - 1.4 to 1.5 Tesla

Lower values should be used for small rating transformers.

III. CALCULATION OF TOROIDAL TRANSFORMER

According to Equation 1 to Equation 17, 15 kVA rating of the variable transformer is designed in this research.

Core Design of Toroidal Transformer

$$\text{Cross section area of iron core} = \frac{\sqrt{15\times10^3}}{5.58}$$

$= 21.949\ in^2$

$= 141.606\ cm^2$

Assume stacking factor (k_s) = 0.9

$$\text{Net-cross sectional area of iron core} = \frac{141.606}{0.9}$$

$= 157.34\ cm^2$

For cold rolled grained oriented silicon steel,

Flux density, B_m = 1.4~1.5 Wb/m^2

Assume flux density, B_m = 1.4 Wb/m^2

Turns per volt,

At K = 0.8,

$E_t = 0.8\sqrt{15} = 3.098$

Turns per volt, $N_e = \dfrac{10}{21.949} = 0.5$ turns/volt

Since the form of the toroidal type transformer is a circular ring, the circumference condition, the inner diameter, the outer diameter, height of the core and the width place take by the winding will be considered first.

Width of the ring face, $A = \sqrt{157.34} = 12.543$ cm

The ratio of the B/A must have 1.5~2 times. In 15 kVA autotransformer design, if A = 9 cm, the height of the core, B, must be 17.483 cm.

Assume inner diameter (d_i) = 12 cm

Inner radius (r_i) = 6 cm

Outer radius (r_0) = r_i + A = 15 cm

So, outer diameter (d_o) = $2r_0$ = 30 cm

Section view of toroidal autotransformer is shown in Fig. 1.

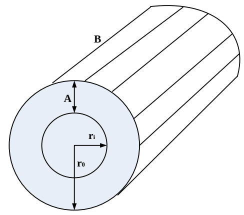

Figure 1. Section View of Toroidal Autotransformer

Winding Design of Toroidal Transformer

In winding design,

S = 15 kVA

V = 250 V

f = 50 Hz

Assume Efficiency, η = 0.9 (90%)

Maximum current rating of the transformer,

$$I = \frac{15\times10^3}{250\times0.9} = 66.67\ A$$

So, S.W.G (6) will be chosen.

From standard wire gauge table,

Net cross-section area = 109.092 mm^2

Diameter of bare conductor = 11.7856 mm

Length for a turn = 2 (A + B)

= 2 (9 + 17.483)

= 52.966 cm ≈ 53 cm

Total length for a winding = mean length for a turn × number of turns

= 53 × 125 = 6625 cm

From standard wire gauge table,

For S.W.G (6),

1000 ft – 111.6lbs

30480 cm – 111.6 lbs

6625 cm – ?

= 24.25 lbs ≈ 25 lbs

Therefore, 25 lbs of the winding will be needed for the SWG (6) of the toroidal transformer. Wiring diagram of toroidal autotransformer is shown in Fig. 2.

Number of winding turns from P to N = 250 × 0.5

= 125 turns

Number of winding turns from A to N = 220 × 0.5

= 110

Number of winding turns from A to P = 15 turns

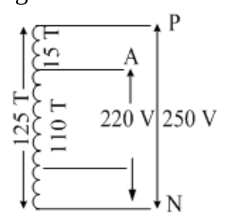

Figure 2. Wiring Diagram of Toroidal Autotransformer

Current rating of each winding, $I_{each} = \frac{66.67}{125} = 0.533$

Current density, $\delta = 2.00$ to 2.5 A/mm^2

Assume, current density, $\delta = 2$ A/mm^2

Cross sectional area of each winding,

$$A = \frac{0.533}{2} = 0.2665 \text{ mm}^2$$

$\pi r^2 = 0.2665$

$r = 0.287$ mm

Diameter of each winding, d $= 2 \times r$ $= 0.574$ mm

Diameter of all winding, d_1 $= 0.574 \times 125$ $= 71.75$ mm

Circumference of all winding $= \pi \times d_1 = 225$ mm

Diameter of core, d_2 $= 9$ cm $= 90$ mm

Circumference of core $= \pi \times d_2 = 282.74$ mm

Spacing of winding $= 282.74 - 225$ $= 57.74$ mm

Spacing of each winding $= \frac{57.74}{125} = 0.462$ mm

Spacing of each winding $= \frac{0.462}{\pi} = 0.15$ mm

The calculated values of toroidal autotransformer are shown in Table II.

TABLE II. DETAILED DESIGN SHEET FOR TOROIDAL AUTOTRANSFORMER

Description	Symbol	Unit	Designed values
kVA Rating	P (or) S	kVA	15
Cross sectional area	A_i	cm^2	141.606
Net cross sectional area	A_{gi}	cm^2	157.34
Turn per volt	N_e	T/V	0.5
Width of ring face of core	A	cm	9
Height of core	B	cm	17.483
Inner diameter	d_i	cm	12
Inner radius	r_i	cm	6
Outer diameter	d_o	cm	30
Outer radius	r_o	cm	15
Current	I	A	66.67
Number of turns	N	-	125
Conductor area	a	mm^2	109.092
Bare diameter	b	mm	11.7856
Length for a turn	-	cm/turn	53
Total length for a winding	-	cm	6625
Pounds of the winding	-	lbs	25
Current of each winding	I_{each}	A	0.533
Cross sectional area of each winding	A	mm^2	0.2665
Diameter of each winding	d	mm	0.574
Diameter of all winding	d_1	mm	71.75
Circumference of all winding	-	mm	225
Circumference of core	-	mm	282.74
Spacing of winding	-	mm	57.74
Spacing of each winding	-	mm	0.15

IV. ROTATIONAL TESTS

During the fluctuation of –40%, +10% servomotor automatic voltage stabilizer will give the following tables. In this region, this stabilizer will produce the stable output voltage 220 V. The variable autotransformer is arranged 0.5 turns per voltage and 180 circular is taken due to the limit switch position. Variable autotransformer with forward condition and reverse condition are shown in Fig. 3 and Fig. 4.

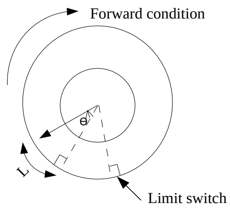

Figure 3. Variable Autotransformer with Forward Condition

When the supply voltage is lower than the output voltage, the variable autotransformer of brush will rotate the clockwise condition.

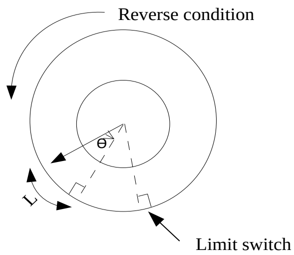

Figure 4. Variable Autotransformer with Reverse Condition

Where; Θ = rotational angle

L = linear displacement

When the supply voltage is higher than the output voltage, the variable autotransformer of brush will rotate the anticlockwise condition.

V. MODE OF OPERATION

During the fluctuation of -40%, +10% servomotor automatic voltage stabilizer will give the following result. The AVS will produce the stable output voltage 220 V. If the supply voltage is equal the output voltage of automatic voltage stabilizer, the servo motor does not run in this condition. Figure 5 shows the output result of servo motor when the input voltage is stable by using Proteus Software. In this figure, the input voltage of microcontroller is 4.34 V for phase R, Y and B.

During the under voltage condition, the input voltage of the stabilizer is lower than output voltage. In this condition, the motor drives in forward direction as to increase the stabilizer output voltage to the 220 V. Figure 6 shows the simulation result of under voltage condition. In this figure, the input voltage of microcontroller is

2.55 V for phase R, 3.73 V for phase Y and 2.96 V for phase B.

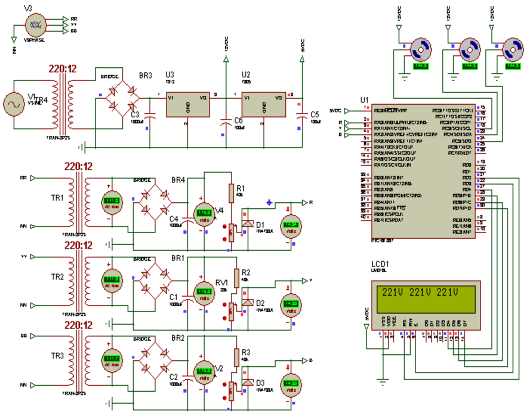

Figure 5. Simulation Result of AVS Controller in Stable Condition

During the over voltage condition, the input voltage of the stabilizer is higher than output voltage. In this condition, the motor drive in reverse direction as to decrease the stabilizer output voltage to the 220 V. Figure 7 shows over voltage condition of servo control system by using Proteus Software. In this figure, the input voltage of microcontroller is 4.52 V for phase R, 4.69 V for phase Y and 4.89 V for phase B.

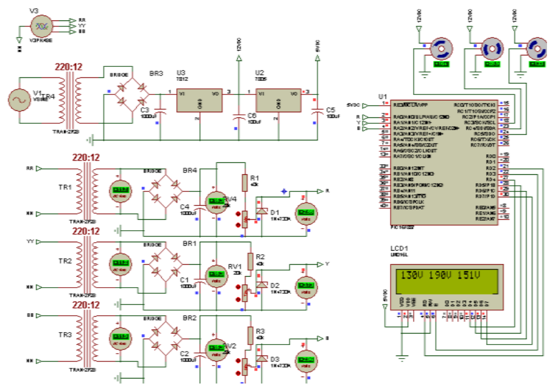

Figure 6. Simulation Result of AVS Controller in Under Voltage Condition

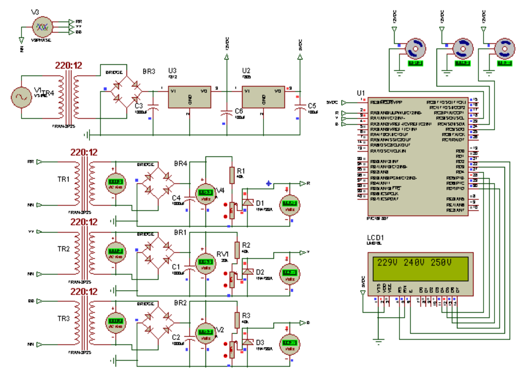

Figure 7. Simulation Result of AVS Controller in Over Voltage Condition

VI. TEST RESULTS OF STABILIZER OUTPUT AT DIFFERENT INPUT VOLTAGES

Table II shows the direction of servo motor depending on the variable input voltage to get nearly the stable output voltage 220 V.

TABLE II. FOR LOW VOLTAGE UP TO – 40 % AND HIGH VOLTAGE UP TO +10%, ANGLE DISPLACEMENT WITH RESPECT TO VOLTAGE FLUCTUATION

Input voltage	Different voltage	Number of turns	Clockwise direction	Output voltage
130	-90	45	164°	218.31
140	-80	40	148°	218.43
150	-70	35	133°	218.53
160	-60	30	127°	218.63
170	-50	25	111°	218.71
180	-40	20	94.5°	218.78
190	-30	15	85.8°	218.84
200	-20	10	68.4°	218.90
210	-10	5	53.3°	221.05
220	-	-	45.1°	221.00
230	+10	5	31.8°	221.05
240	+20	10	14.7°	221.09
250	+30	15	6.72°	221.14

In this research, when the voltage fluctuation is lower than 130 V and higher than 250 V, the servo control automatic voltage stabilizer is automatically shut down and does not operate in this situation. The servo motor automatic voltage stabilizer will nearly produce the stable output voltage 220 V.

CONCLUSIONS

Test outcome shows that the output voltage remains virtually constant at varying input voltage. However, at extremely low voltages below 130V there was no output voltage because the switching device is not even activated. On the other hand, at voltages beyond 250V the system protection is activated and no output voltage. Therefore the research has made it possible for the device to operate from as low as 130 V. The primary objective of this work which was to improve the performance of conventional AC voltage stabilizer was achieved. The work was designed in consideration with some factors such as economy, availability of components, efficiency, compatibility, portability and durability.

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REFERENCES

[1] BartloiejBelko, M. C.: The Conception and Implementation of Control System for Servo Motor with Application of Local Area Network, Cracow, (2010).

[2] Metrel: Single-phase Built-in Variable Transformer, Three-phase Built-in Variable Transformer, Motor

Driven Variable Transformer, Desk top Variable Transformer, (2009). http://www.netrel.si
[3] Hans Beijher: Output Transformers and Magnetic Formulas, Prentice-Hall, Noord-Holland, Netherlands, (2004).
[4] Matt Ruff: Servomotor Control Application, Freescal Semiconductor Inc., Japan, (2004).
[5] Biswanath Paul: Industrial Electronics and Control, Prentice-Hall of Private Limited, India, (2001).
[6] Chuck McManis: Servo Basic, Omron Asia Pacific Pte, Ltd., Korea, (2000).
[7] Mark Readman: Motors, Seimens Company, London, (1997).
[8] Bhopal: Design of Electrical Machines, Standard Publisher Distributors, 4th Ed., 1705-E, NalSarak, DELHI-110006, (1996).
[9] Patchett, G.N.: Automatic Voltage Regulators and Stabilizers, Sir Isaac Pitman and Sons Ltd., 2nd Ed., Canada, (1954).