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ELECTRICAL POWER ENGINEERING

Design and Construction of 20 kVA Automatic Voltage Stabilizer Control System

Su Hlaing Myint#1, Salai Tluang Za Thang*2
#Department of Electrical Power Engineering, Technological University (Sittwe), Sittwe, Myanmar
*Mandalay Technological University
Mandalay, Myanmar
1suhlaingmyint.mtu@gmail.com
2tzthang@gmail.com

***Abstract*— Automatic voltage stabilizer is essential needed for industries in Myanmar. Both single-phase and three-phase are available. In this research paper, automatic voltage stabilizer intends to three-phase unbalanced loads because most of the industries used in unbalanced load. Automatic voltage stabilizer consists of two units; measuring unit and regulating unit. In this automatic voltage stabilizer, variable autotransformer is used for the regulating unit and electronic control circuit is used for sensing unit. The main purpose of this research is the design and construction of servo control circuit.**

In this paper, control circuit for automatic voltage stabilizer provides voltage comparators, relays, presets and servomotor that compare instantaneous input and output voltage. This value can be adjusted in the electronic control circuit until the desired voltage is reached. At that time, the output of measuring unit is zero. Servo motor is attached to rotate the brush arm of the variable autotransformer until the output voltage is stable.

The electronic control circuit will operate within the fluctuation range from 130 V to 250 V and 20 kVA (single-phase) is designed. The output sensitivity is ±1%. Its frequency range is 50 Hz. The feature of this stabilizer is the input wave form equal to the output wave form. As a phase loss sensing, phase sensing bridges are used. If the input voltage is lower than 130 V or higher than 250 V, the system will be automatic shutdown.

Keywords— voltage comparators, relays, presets, servo motor, step down transformers

I. Introduction

The problem of the maintenance of constant voltage covers an extremely large field, from the control of the bus bar voltage of a power station to the supply of constant voltage to small electronic instruments. In the former the power may be in hundred of megawatts, while in the later case it is only a few watts or even a fraction of a watt. According to the nature of electricity, voltage fluctuation is common in any electrical supply system. Continuous variation of loads and extension of power lines are the main factors which contribute to the above problem.

In general, most electrical or electronic equipment are designed to operate within a voltage fluctuation of ± 10% of its rated supply. Automatic voltage stabilizes using servo systems are quite common. Anywhere that there is an electric motor there will be a servo control system to control it. Servo control is very important. The economy of the world depends upon servo control. Manufacturing industries would cease without servo system because factory production lines could not be controlled, transportation would halt because electric traction units would fail, computers would cease because disk drives would not work properly and communications networks would fail because network servers use hard disk drives. So, servo control systems are that it is vital to know about them. This servo control system is also used in AVS.

Both single phase and three phase types are available. The rating of this type of stabilizer is quite high and is more economical for high power rating. Servo control automatic voltage stabilizer provides a continuous monitoring of the output voltage by means of an electronic control circuit that compares the instantaneous output voltage with the set value. When changes are detected due to fluctuation of supply voltage or sudden changes in load, an electrical signal will be transmitted to the servo motor which is coupled onto the brush gear of the variable transformer, which causes the brush gear to rotate until the appropriate voltage is restored. This method of stabilization does not create interference nor harmonics in the supply system.

II. SERVO SYSTEM AUTOMATIC VOLTAGE STABILIZER

The automatic voltage stabilizer consists essentially of two main parts: 1. regulating unit and 2. measuring unit

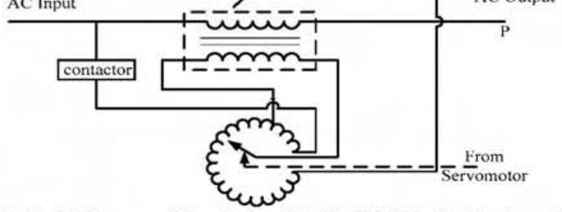

Fig. 1 Block Diagram of Regulating Unit for 20 kVA, Single-phase AVS

The regulating unit consists the buck-boost transformer and variable autotransformer. The purpose of the regulating unit is that of acting, under the signal from the measuring unit, in such a manner as to correct the output voltage of the stabilizer, as near as possible, a constant or predetermined value. In some cases, a unit is required to control the regulating unit and this is termed the controlling unit. It is sometimes necessary to introduce another unit to prevent hunting, a continual fluctuation or oscillation of voltage stabilizer. This part will be referred to as the anti-hunting unit. Fig. 1 shows the block diagram of a regulation unit of automatic voltage stabilizer.

Measuring unit includes control circuit. The function of the measuring unit is that of detection a change in the input or output voltage of the automatic voltage stabilizer and producing a signal to operate the regulating unit. Fig. 2 show the block diagram of a measuring unit of automatic voltage stabilizer.

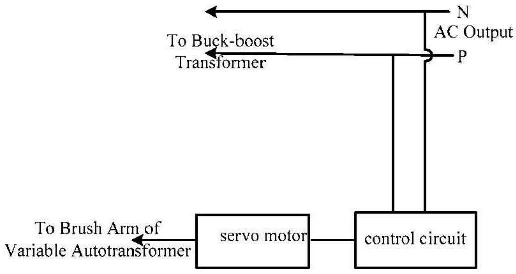

Fig. 2 Block Diagram of Measuring Unit for 20 kVA, Single-phase AVS

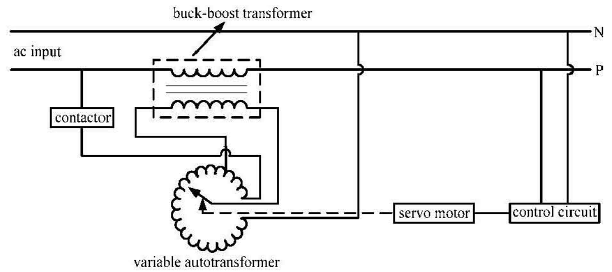

Fig. 3 Complete Block Diagram of a Servo Controlled Automatic Voltage Stabilizer for Single-Phase

Three phase stabilizers consist of three single phase stabilizers connected in star.

III. RESEARCH PROCEDURE OF SERVO CONTROL CIRCUIT FOR AVS

The output voltage of the stabilizer is stepped down by transformer to 17 V and 13V. And then 17V transformer output is rectified by the bridge rectifier B_1. The rectified voltage is filtered by capacitor.

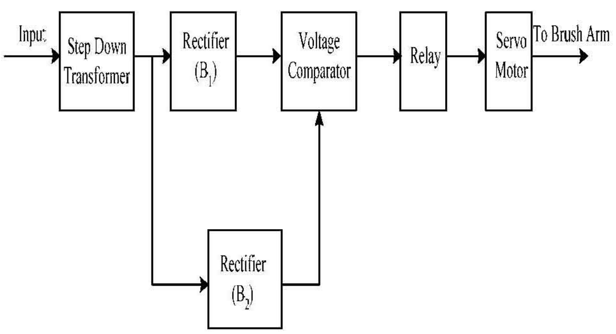

Fig. 4 Block Diagram of Servo Control System for 20 kVA Automatic Voltage Stabilizer

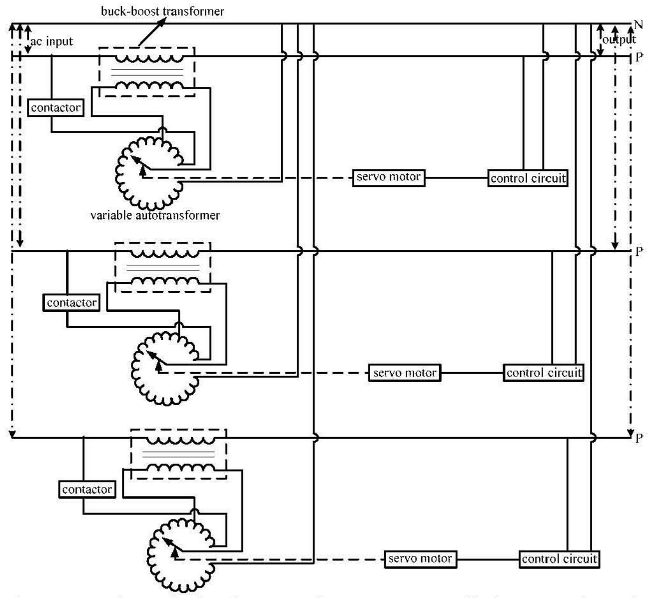

Fig. 5 Complete Block Diagram of a Servo Controlled Automatic Voltage Stabilizer for Three-phase

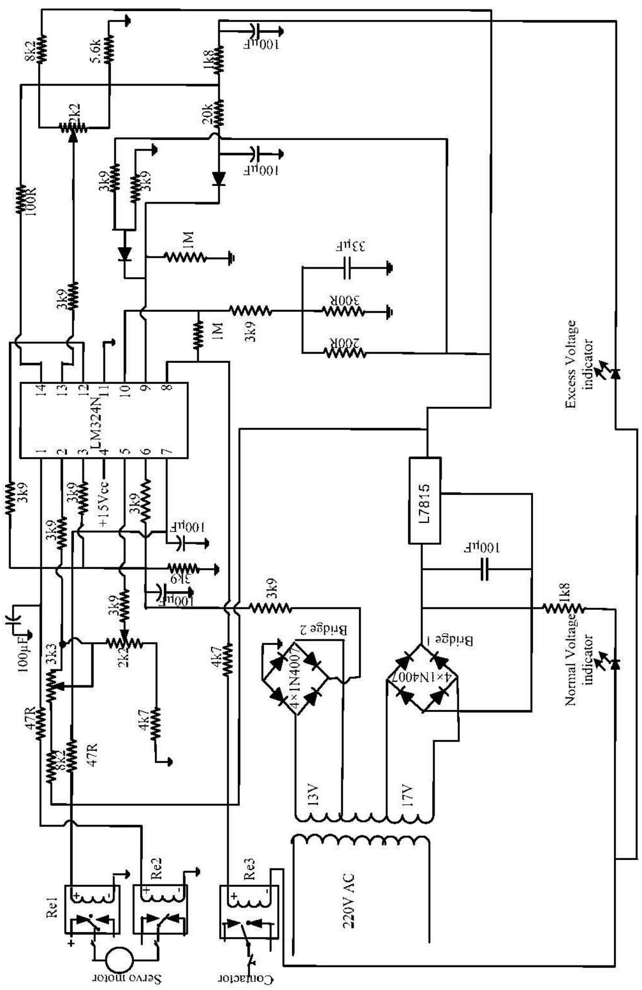

Fig. 6 Circuit Diagram of Servo Control System for 20 kVA Automatic Voltage Stabilizer

The 13V transformer output is rectified by the bridge rectifier B_2. And then, the appeared voltage is compared with a reference obtained from bridge B_2 in an op-amp LM324N. The capacitor 33 µF is charged by DC supply charge from the voltage regulator IC L7815. Three DC relays are put at the output of the op-amps. The relay Re_3 can be driven the contactor contacts. The DC servo motor is connected through the contacts of the relays in such a way that it can be driven in both directions.

At the normal condition, the contactor is ON by the relay Re_3. If the output of the stabilizer is equal to the desired value, the op-amp output is zero. If the input voltage of the stabilizer is lower than output voltage, the sensing circuit is unbalanced in such direction that the op-amp output is positive. Relay Re_1 is energized and relay Re_2 is OFF. The motor rotates in such a direction as to increase the stabilizer output voltage up to the desired value. At this condition, relays are off and motor is stop. The wiper of the variable transformer remains in the new position. If the stabilizer output voltage becomes high, bridge rectifier R_2 voltage changes and relay Re_2 is energized rotating the motor in the other direction so that the output voltage becomes nominal and both the relays are again OFF. When the voltage fluctuation is lower than 130 V and higher than 250 V, the control system is automatically shut down.

IV. Design Consideration

Automatic voltage stabilizer control system is based on mainly two categories such as power supply system and control circuit.

4.1 Power Supply System

A power supply is an essential part of each electronic system from the simplest to the most complex. Input voltage supply is 220 V AC primary; secondary voltage is chosen 13 V for sensing unit and 17 V for regulated power supply.

The power supply in this project, the step-down power transformer is used. The transformer using the circuit is shell type because it need low voltage and high output.

For regulated power supply,

The primary to secondary ratio is,

$$\frac{V_s}{V_p} = \frac{N_2}{N_1}$$

$$V_s = \frac{N_2}{N_1} V_p$$

$$17 = \frac{N_2}{N1} \times 220$$

$$\frac{N_2}{N_1} = 0.077$$

In this transformer, the input voltage is 220, the secondary voltage is 17V. In this circuit, the full wave rectifier is used. It is the process of converting alternating current or voltage into direct current or voltage.

The peak voltage at the primary is

$$V_p = \sqrt{2} \times V_{rms}$$

$$= \sqrt{2} \times 220 \qquad = 311.13 \text{ V}$$

The peak voltage at the secondary is

$$V_s = \sqrt{2} \times V_{rms}$$

$$= 1.414 \times 17 = 24.038 \text{ V}$$

$$V_{out} = 24.038 - 1.4 = 22.638 \text{ V}$$

In this circuit, the three terminals fixed voltage regulator IC, L7815, which produces positive 15 V only. The filter capacitors are used for pure DC output. Their ratings are 100µF, 25 V.

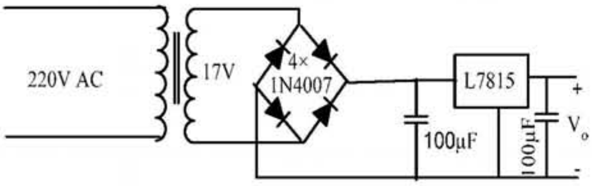

Fig. 7 Power Supply for Control Circuit

And then, for sensing portion, from Equation 4.11,

$$V_s = \frac{N_2}{N_1} \times V_p$$

$$13 = \frac{N_2}{N1} \times 220$$

$$\frac{N_2}{N_1} = 0.059$$

In this transformer, the input voltage is 220, the secondary voltage is 13V. In this circuit, the full wave rectifier is used. The unstable voltage is compared with a reference obtained in the operational amplifier LM 324N.

The peak voltage at the primary is

$$V_s = \sqrt{2} \times V_{rms}$$

$$= \sqrt{2} \times 220 \qquad = 311.13 \text{ V}$$

The peak voltage at the secondary is

$$V_s = \sqrt{2} \times V_{rms}$$

$$= 1.414 \times 13 = 18.382 \text{ V}$$

$$V_{out} = 18.382 - 1.4 = 16.982 \text{ V}$$

The V_{out} is variable with respect to input voltage supply.

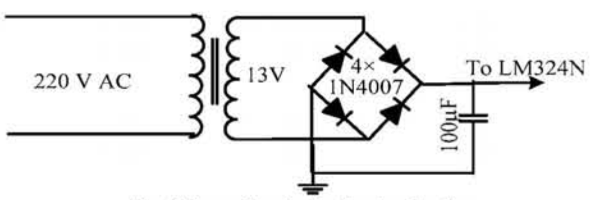

Fig. 8 Power Supply for Sensing Portion

4.2 Control Circuit System

In this thesis, 20 kVA single-phase is only considered.

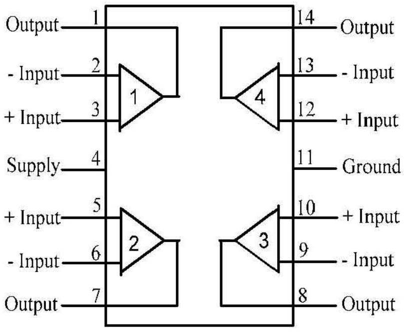

Fig. 9 Diagram of Pin Function of LM324N

In Fig. 9, three operational amplifiers act as voltage comparators and one is switching circuit of the op-amp. There are three conditions by the unstable input supply. In the project, op-amp3 of LM324N is acted as timing circuit at normal condition. This function may be accomplished by using positive feedback in the voltage comparator circuit. It reduces switching time of op-amp. If the input voltage supply is 220V, the capacitor 33 μF will be full of charge and op-amp 3 start work and then the relay R_{e3} becomes energized and the contactor is ON.

(a) Normal Condition

The parameters of op-amp 3,

From data sheet of LM324N, gain $A_v = 1$, so $V_o = V_{in}$

$V_{in} = V_2 - (-V_1)$

When V_2 is greater than V_1, the output is at its maximum positive limit.

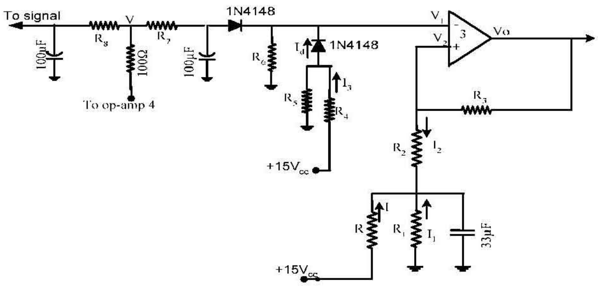

Fig 10. Circuit Diagram for Op-amp 3 of LM324N

Assume, the inverting input $V_1 = -6$ V

the non-inverting input $V_2 = 7$ V

According to input-output relations of voltage comparator,

$V_{out} = V_2 - (-V_1) = 7 - (-6) = 13$ V

Let the voltage at node V = 6.98 V

Apply the KCL,

$$\frac{V_2 - V_1}{R_2} + \frac{V_2 - V_o}{R_3} = 0$$

If $R_2 = 3.9$ kΩ, $R_3 = 1.17$ MΩ

∴ The standard value of $R_2 = 3.9$ kΩ and $R_3 = 1$ MΩ are chosen.

And then, $I_2 = \frac{V}{R_2} = \frac{6.98}{3.9\ \text{k}\Omega} = 1.789\ \text{mA} \approx 1.8\ \text{mA}$

From dada sheet of L7815CV, $V_{cc} = 15$ V, $I_o = 5$ mA to 1 A.

So, assume $I_o = 80$ mA

By Ohm's Law,

V = IR

$$R = \frac{15}{80\ \text{mA}} = 197.5\ \Omega \approx 200\ \Omega$$

The standard value of R = 200 Ω is selected.

By KCL, $I_1 = I + I_2 = 80\text{ m} + 1.8\text{ m} = 81.8$ mA

$V_R = 25$ V (∵ R_1// 33μF)

$$R_1 = \frac{25}{81.8\text{m}} = 305.623\,\Omega \text{ (standard value } 300\Omega)$$

Next, let $I_3 = 3.85$ mA from data sheet of L7815 CV

$$\therefore R_4 = \frac{15}{3.85} = 3.9\text{k}\Omega$$

In the project, switching diode 1N 4148 is used.

Assume $I_d = 0.025$ mA (from data sheet)

By KCL,

$I_5 = I_3 - I_d = 3.85\text{ m} - 0.025\text{ m} = 3.825$ mA

I_5 is approximately equal to Is. So, $R_4 \approx R_5$

∴ $R_5 = 3.9$ kΩ

In this circuit, capacitors 100 μF, 25 V are used for frequency compensated and smooth the output signal. Switching diode 1N 4148, voltage drop = 1 V from data sheet

$I_6 = 0.025$ mA

By KVL,

$-25 + 1 + I_6R_6 = 0$

$R_6 = 0.96$ MΩ

The standard value of 1 MΩ is selected.

Next, let node V= 1.43 V and R = 100 Ω

By nodal equation,

$$\frac{V-25}{R_7} + \frac{V-25}{R_8} + \frac{V}{100} = 0$$

$1.65\text{k}R_7 + 1.65\text{k}R_8 = R_7 R_8$

If $R_7 = 1.8$ k, $R_8 = 19.8$ kΩ ≈ 20 kΩ

So, $R_7 = 1.8$ k and $R_8 = 20$ kΩ are chosen.

sIn this condition, output voltages of the left three op-amps are zero, relays R_{e1} and R_{e2} are OFF and motor does not run.

(b) Over voltage condition

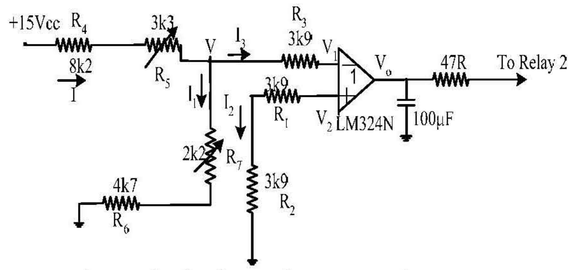

Fig. 11 Circuit Diagram for Op-amp 1 in LM324N

The parameters of op-amp1,

From data sheet of LM324 N, gain $A_v = 1$, so $V_o = V_{in}$

$V_{in} = V_1 - V_2$

Assume, the inverting input V_1 = 5 V
the non-inverting input V_2 = 6.8 V
Assume I_2 = 0.87 mA

$V_2 = I_2 \times R$, ($R = R_1 + R_2$)

$$R = \frac{V_2}{I_2} = \frac{6.8}{0.87\ m} = 7.8125\ k\Omega$$

Let $R_1 = R_2$
Therefore, the same resistors R_1 = 3.9 kΩ and R_2 = 3.9 kΩ are used in series.
Let voltage at node V= 5.5 V,
$V_{R3} = V - V_1 = 5.5 - 5 = 0.5$ V
I_3 = 0.13 mA

$$R_3 = \frac{V_{R3}}{I_3} = \frac{0.5}{0.13\ m} = 3.85\ k\Omega$$

So, the standard value of R_3 for this condition is chosen as R_3 = 3.9 kΩ. Let I_1 = 0.85 mA

$$R_6 + R_7 = \frac{V}{I_1} = \frac{5.5}{0.85\ m} = 6.47\ k\Omega$$

If R_6= 4.7 kΩ is used, then
R_7 = 6.47 kΩ - 4.7 kΩ = 1.77 kΩ
So, the preset R_7 is connected in series with R_6.
The standard value of preset resistor R_7 is 2.2 kΩ.

Next, $\frac{15 - V}{I} = R_4 + R_5$

$$\frac{15 - 5.5}{I_1 + I_3} = R_4 + R_5$$

$9.694 = R_4 + R_5$
If R_4 = 8.2 kΩ is used then
R_5= 9.694 - 8.2 = 1.5 kΩ
For gain $A_v = 1$, $V_o = V_{in}$
$V_{in} = V_1 - V_2 = 5 + 6.8 = 11.8$ V

The preset R_5 is connected in series with R_4. The standard value of preset resistor R_5 is chosen as 3.3 kΩ to adjust the over voltage. The capacitors in each of the amplifiers provide frequency compensation for unity gain. In above condition, relay Re_2 is energized and rotate the motor to a direction so that the output voltage becomes nominal.

(c) Under voltage condition
The parameters of op-amp2,
Let, V_1= 5 V and V_2= 5.2 V, I_1=0.49 mA,

$$R_1 + R_2 + R_3 = \frac{V_2}{I_1}$$

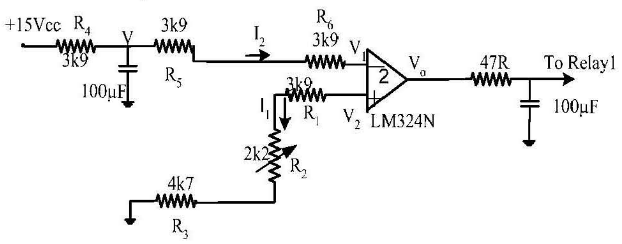

Fig 12. Circuit Diagram for op-amp 2 in LM324N

$$R_2 = \frac{V_2}{I_1} - (R_1 + R_3)$$

$$= \frac{5.2}{0.49\ m} - (3.9k + 4.7k)$$

R_2= 2.2 kΩ
For gain $A_v = 1$, $V_o = V_{in}$
$V_{in} = V_1 - V_2 = 5 + 5.2 = 10.2$ V

The choice value of preset resistor R_2 is 2.2 kΩ. When the voltage is low, relay Re_1 is energized and rotate the motor to the other direction until desired voltage is reached.

(d) Over 250V Limit Condition
The parameters of op-amp4,
From data sheet of L7815CV, Io= I = 1.09mA
By Ohm's Law,
V= IR

$$R_6 = \frac{15 - V}{1.09m} = 8.256\,k\Omega \approx 8.3k\Omega$$

When V_2 is greater than V_1, the output is at its maximum positive limit.
Assume, the inverting input V_1 = 5 V
the non-inverting input V_2 = 7 V
I_2=0.89mA

$$R_6 = \frac{15 - V}{1.09m} = 8.256\,k\Omega \approx 8.3k\Omega$$

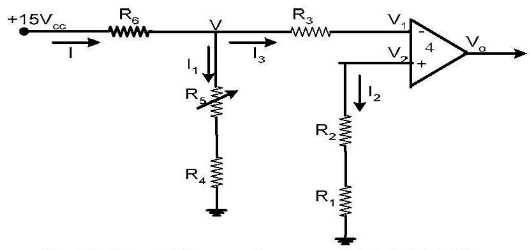

Fig 13. Circuit Diagram for op-amp 4 in LM324N

When V_2 is greater than V_1, the output is at its maximum positive limit.
Assume, the inverting input V_1 = 5 V
the non-inverting input V_2 = 7 V
I_2=0.89mA
For gain $A_v = 1$, $V_o = V_{in}$
$V_{in} = V_1 - V_2 = 5 + 7 = 12$ V
$V_2 = I_2 R$ (i.e. $R = R_1 + R_2$)

$$R = \frac{7}{0.89\ m} = 7.8125\ k\Omega$$

If R_1=3.9 kΩ, R_2 = 3.9 kΩ
The same two resistors R_1 and R_2 are connected in series.
From data sheet of LM 324N, $I_{in} = I_3$ = 0.256 mA
Let voltage at node V= 6 V,

$$R_3 = \frac{V - V_1}{I_3} = \frac{6 - 5}{0.256} = 3.85\,k\Omega$$

The practical value for R_3 is 3.9k Ω
$I = I_1 + I_3$

$I_1 = 0.833mA$

Next, $R_5 + R_4 = \frac{V}{I_1} = \frac{6}{0.833m} = 7.202\ k\Omega$

If $R_4 = 5.6\ k\ \Omega$, $R_5 = 1.6\ k\Omega$. So the standard value of variable resistor 2.2 kΩ is used.

In this condition, relay R_{e3} is de- energized, cut off the voltage and all of the operation system is stopped.

V. TEST RESULTS

5.1 Rotational Test

During the fluctuation of – 40%, + 10% servomotor automatic voltage stabilizer will give the following tables. In this region, this device will produce the stable output voltage 220 V. The variable autotransformer is arranged 0.947 turns per voltage and 350˚ circular is taken due to the limit switch position.

When the supply voltage is lower than the output voltage, the brush will rotate the clockwise direction. The buck-boost transformer will add the required value to the supply voltage.

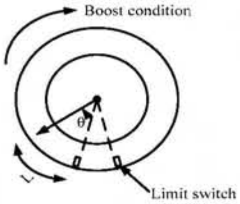

Fig 14. Variable Autotransformer with Boost Condition

Where θ = rotational angle

L = linear displacement

When the supply voltage is higher than the output voltage, the brush will rotate the anticlockwise direction. The buck-boost transformer will subtract the exceed value from the supply voltage.

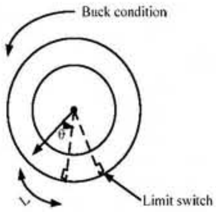

Fig 15. Variable Autotransformer with Buck Condition

TABLE I
RESULTS FOR LOW VOLTAGE UP TO – 40%

Input Voltage	Output voltage	Difference voltage	Clockwise direction	Linear displacement mm	Times
210	220	- 10	22.20˚	27.90	3.8
200	220	- 20	44.41˚	55.80	7.6
190	220	- 30	66.61˚	83.70	11
180	220	- 40	88.82˚	111.609	15.2
170	220	- 50	111.02˚	139.512	19
160	220	- 60	133.188˚	167.414	22.8
150	220	- 70	155.428˚	195.316	26.6
140	220	- 80	177.632˚	223.219	30.5
130	220	- 90	199.836˚	251.122	34.3

TABLE II
RESULTS FOR HIGH VOLTAGE UP TO + 10%

Input Voltage	Output voltage	Difference voltage	Clockwise direction	Linear displacement mm	Times
230	220	+ 10	22.20˚	27.90	3.8
240	220	+ 20	44.41˚	55.80	7.6
250	220	+ 30	66.61˚	83.70	11

If the supply voltage is less than 130 V and more than 250 V, the supply of the motor will be cut out. After that the circuit breaker will cut out the supply. So, servomotor automatic voltage stabilizer will not produce the power supply without being 220 stable voltages.

5.2 Servo Control Circuit Tests

During the fluctuation of –40%, +10% servomotor automatic voltage stabilizer will give the following results. In this region, this device will produce the stable output voltage 220 V. These figures show the various voltage condition of control circuit.

When the supply voltage is equal the output voltage, op-amp-3 in LM324N starts work and then relay-3 is on. At that time motor does not run which condition displays LED. Fig 16. shows output simulation curve at normal voltage condition that the output voltage is 13.35 V by testing in circuit maker software.

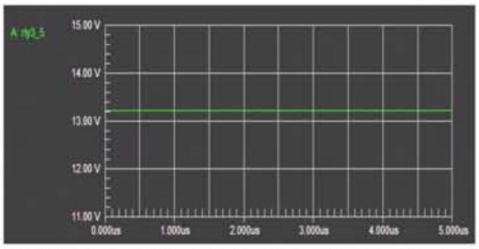

Fig. 16 Output Simulation Curve for Pin-8 of Op-amp 3 in LM324N at Normal Condition

Fig. 17 Photo Showing 20 kVA, Automatic Voltage Stabilizer Control System at Normal Condition

During the under voltage condition, the input voltage of the stabilizer is lower than output voltage, the sensing circuit is unbalanced that and the op-amp output is positive. Relay Re_1 is energized and relay Re_2 is OFF. The motor rotates clockwise direction as to increase the stabilizer output voltage to the 220V. Fig18. shows output simulation curve at under voltage condition that the output voltage is 13.35 V by testing in circuit maker software.

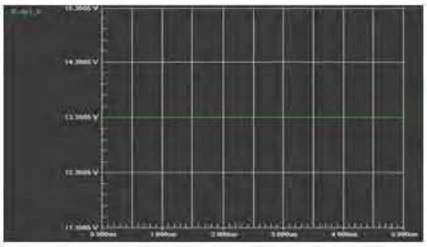

Fig 18.Output Simulation Curve for Pin-7 of Op-amp 2 in LM324N at Under Voltage Condition

Fig 19. Photo Showing 20 kVA, Automatic Voltage Stabilizer Control System at Under Voltage Condition

During the over voltage condition, the input voltage of the stabilizer is higher than output voltage, the sensing circuit is unbalanced that and the op-amp output is positive. Relay Re_2 is energized and relay Re_1 is OFF. The motor rotates anti-clockwise direction as to decrease the stabilizer output voltage to the 220V. Fig 20. shows output simulation curve at over voltage condition that the output voltage is 13.35 V by testing in circuit maker software.

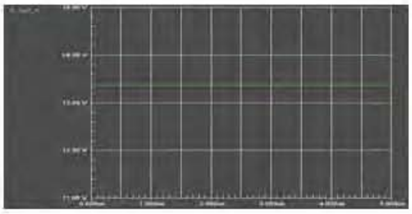

Fig 20. Output Simulation Curve for Pin-1 of Op-amp1in LM324N at Over Voltage Condition

Fig 21. Photo Showing 20 kVA, Automatic Voltage Stabilizer Control System at Over Voltage Condition

VI. DISCUSSION

In Myanmar, the voltage fluctuation always occurs in industries with respect to time. Due to the voltage fluctuation of voltage, life of all electrical equipment is shorted really. To clear this problem, automatic voltage regulator and automatic voltage stabilizer are appeared. Difference between AVR and AVS are: AVR is relay type and AVS is servo type continuous controlling with electronic circuit and its response time is faster and more accurate than AVR. Sensing unit of AVS is better than AVR.

Automatic voltage stabilizer plays an important role in daily life of industries. Various motors may be used for regulating unit. But, in automatic voltage stabilizer, servomotor is used because it had the advantages of good operation and efficiency, controllability, cheaper cost, having smooth continuous motion capabilities, rotating the motor until heavy loads are placed, controlling more precisely the position of an object. It is compact size and light weight. In servo control circuit, a sensing unit, voltage comparator IC to drive the servo motor in desired position. In the device, limit switches are coupled in series with the motor to interrupt the motor supply when variable autotransformer reaches either the upper or lower limit of its voltage.

VII. CONCLUSION

In this research work has focused on the 20 kVA electro-mechanical type automatic voltage stabilizer using servo control system. Servo control system has two positions. One is 12 V DC servo motor and the other is servo control circuit to drive the servo motor and adjust the stable output voltage. In this circuit when the input voltage is lower than 220 V, the relay starts energized and the motor rotates the clockwise direction. And then the input voltage is higher than 220 V, the motor rotates the anticlockwise direction. Signal indicators are monitored the above these conditions. In summary, servomotor automatic voltage stabilizer can be constructed single-phase and three-phase. In this research, the input voltage fluctuation can be withstand 130 V to 250 V for single-phase 20 kVA and its response times are 34.3 seconds at 130 V and 11 seconds at 250 V.

Function of electro-mechanical type automatic voltage stabilizer is very simple. Servo control circuit is also simple. The components of servo control circuit are available in local market. This automatic voltage stabilizer is very convenience and economic for industries. If the electronic control circuit components are damaged, they can be replaced easily. So, servomotor automatic voltage stabilizer having with these conditions will offer the stable output voltage or stable input voltage for all electrical equipments and will improve productivities and reduce downtime.

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