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MODELING AND SIMULATION OF AUTOMATIC VOLTAGE CONTROL RELAY

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Abstract— *Today voltage control is necessary for electrical power system for both at distribution and transmission levels. Present voltage control in distribution networks is primarily carried out by On Load Tap Changing (OLTC) transformers and Automatic Voltage Control (AVC) relays, which is mostly used in 11kV network. The AVC relay, acting on the secondary control of the OLTC transformer, is designed for passive distribution networks with unidirectional power flows. The increasing connection of distributed generation in a distribution network may lead to unacceptable voltage rise. Hence the capacity of distributed generation that may be connected to a distribution networks is limited by the operation of the AVC relay. By measuring critical voltage points along a distribution feeder, an automatic voltage reference setting device is applied to the AVC relay voltage reference setting. The AVC relay and the OLTC transformer are then used to control voltage rise in distribution networks with distributed generation. A number of factors that can influence the optimum tap position are primary voltage level, load level, power factor, distributed generation and circulating current. This thesis presents, firstly, an overview of automatic voltage control methods for transformers and also presents an attempt to design an AVC relay based on Fuzzy Logic. It has been observed that fuzzy logic based control has simple and fast controlling, simplify design complexity and reduce the hardware costs etc. The structure of the proposed Fuzzy Logic based-AVC relay is presented and the results that show its performance into distribution network are also presented and discussed.*

Keywords*— On Load Tap Changing (OLTC) transformers, Automatic Voltage Control (AVC) relays, Fuzzy Logic based-AVC relay*

I. INTRODUCTION

1.1 Background

The electric power is generated in large generating stations at a relatively small number of locations. This electric power is transmitted through transmission line from generating station to receiving station where load is connected. Here 33kv programmable power generation is considered. In these stations, the voltage is stepped up to high voltage (HV) to be transmitted over long distances through an interconnected HV transmission network. The voltage is then stepped down to medium voltage (MV) and low voltage (LV) to the receiving station.

At any point, where a change of voltage level is required, transformer must be applied. Such transformers are usually built with fixed turn-ratios, or sometimes they are equipped with tap terminals for turn-ratio control (OLTC). The operation of the tap changer may be twofold: off load tap changer, or on load tap changer.

One of the simplest and most inexpensive methods of controlling the supply voltage of a distribution system is to employ On-Load Tap-Changer' Transformer with tap changer device installed at the high tension side. It is well known that the transformer impedance varies with the tap positions of OLTC owing to the cutting out of appreciable proportion of winding.

There are essentially two ways to regulate the voltage level, injection of reactive power and transformer regulation. The first method is an indirect method of voltage control in which voltage regulation is accomplished by adjusting the reactive power. The second method is a direct method in which the transformer ratio is physically altered to effect a change in the secondary voltage with respect to the primary. To achieve this the transformer has its low tension winding 'tapped out', so that a switching mechanism referred to as a tap changer can switch more or less of the transformer winding into the circuit. This alters the ratio between the primary and secondary circuit therefore changing the voltage on the transformer output. Voltage fluctuations that are normally the result of varying loads that are connected to the distribution system throughout the day.

1.2 Objective

Here is an attempt to design an AVC relay based on Fuzzy Logic. The structure of the proposed Fuzzy Logic based AVC relay is presented and the results that show its performance. Fuzzy logic systems are simple, and fast. They reduce the design development cycle, simplify design complexity, improve control performance, simplify implementation and reduce the hardware costs.

2. Principle of Automatic Voltage Control Relay

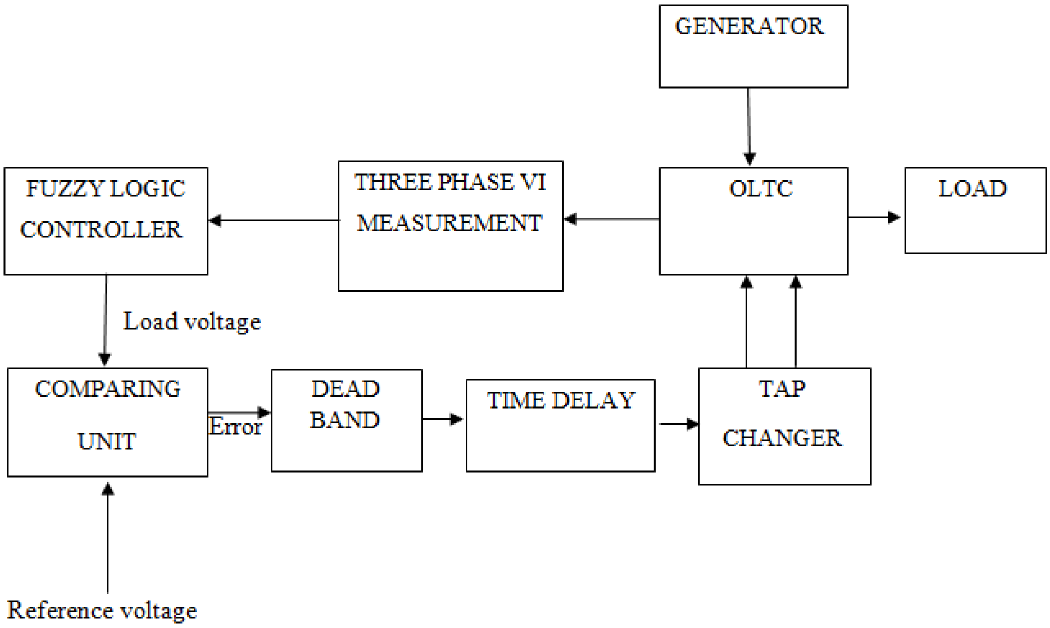

Figure.1. Block diagram of AVC relay

2.1. Fuzzy logic controller:

Fuzzy logic controller takes the input from measuring element. It takes active power and from that it generates load voltage by using **if-then rule** and that output is compared with reference voltage and it will generate error. In consideration of the complexity of voltage and reactive power control, fuzzy logic control theory is considered to apply in the control. Fuzzy control is a new control method based on fuzzy mathematics, which qualifies the variable through fuzzy set theory, expresses people's experience in fuzzy conditional statement and generates control strategy using fuzzy reasoning.

3. METHODS FOR AUTOMATIC VOLTAGE CONTROL RELAY

When automatic load-tap-changing transformers operating in parallel are located remotely from each other, interconnecting control wires are impractical and a modification of the line-drop compensator setting is necessary to obtain satisfactory operation. This type of control is sometimes referred to as the "reduced" or "reversed" reactance method. This method serves to distinguish between circulating current and load current and does this by virtue of a difference in power factor between these currents. A compensator which employs normal resistance and reverse reactance results in a characteristic such that high power-factor currents cause the transformer to increase the voltage and low power-factor currents cause it to decrease. In general, the impedance loop comprising the parallel circuits has a very low ratio of resistance to reactance, and hence the circulating-current power factor usually will be appreciably lower than full-load power factor. Thus, it is possible to set compensators so that load currents will cause a boosting operation and circulating currents will cause a slight bucking operation of transformers with no intervening impedance.

These are the two methods from which can control the AVC Relay.

1. Negative Reactance Compensation

2. Line drop compensation

3.1. Circulating Currents

$$I = \frac{E_1 - E_2}{Z_1 + Z_2}$$

Where
I = circulating current in secondary winding

E_1 = open-circuit no-load voltage of transformer no. 1
E_2 = open-circuit no-load voltage of transformer no. 2
Z_1 = sum of line impedance and transformer impedance of transformer no. 1
Z_2 = sum of line impedance and transformer impedance of transformer no. 2.
Z_1 and Z_2 are measured between the points in the lines where the transformers are connected in parallel.

3.2. Negative-Reactance Compounding Arrangement

Phasor Diagram:

The current and voltage relations of the circuits of Fig. 3.1 are shown by the phasor diagram of Fig..2.
V= voltage at load center
E =voltage equal to no-load voltage maintained by voltage control relay
$\mathbf{V_1}$=voltage at transformer terminals
$\mathbf{R_L}$= line resistance from each transformer to the load center
$\mathbf{X_L}$=line reactance from each transformer to the load center
$\mathbf{R_C}$=compensator resistance; this resistance has a negative sign
Xc = compensator reactance (reversed); this reactance has a positive sign
R = effective resistance = R_L+R_C
X = effective reactance = Xc+X_L**θ** = power-factor angle
p= cos θ

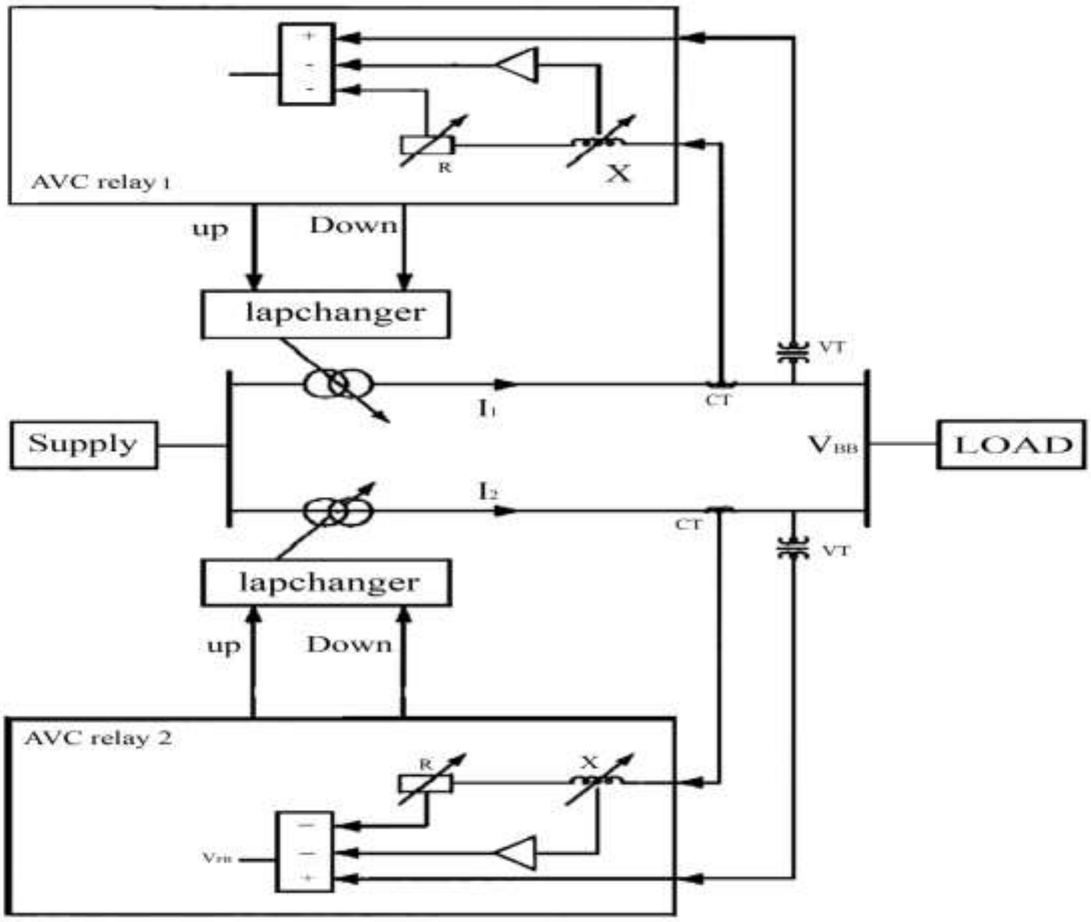

Figure.2. complete circuit of reverse reactance compensation control.

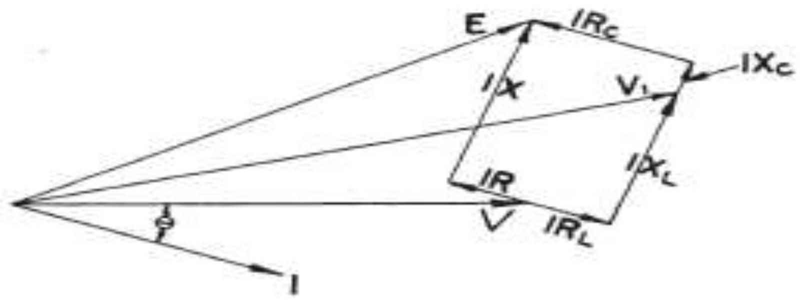

Figure.3. Phasor diagram of Negative-Reactance compensation

Equations:

Equations giving the relationship between E and V may be developed from the phasor diagram of Fig. 3.2 as follows: Assuming V as the reference phasor for the horizontal axis

$$E = (V + IRp + IXq) + j(IXp - IRq) \tag{3.1}$$

$$E^2 = (V + IRp + IXq)^2 + (IXp - IRq)^2 \tag{3.2}$$

For taking relation between E and V dividing equation (3.2) both side by E^2

$$\left(\frac{V}{E} + \frac{IRp}{E} + \frac{IXq}{E}\right)^2 + \left(\frac{IXp}{E} - \frac{IRq}{E}\right)^2 = 1$$

Let. $\frac{IR}{E} = r$ And $\frac{IX}{E} = x$

$$\frac{V}{E} = \sqrt{1 - (xp - qr)^2} - (pr + qx) \tag{3.3}$$

For some purposes, the equations developed assuming I as the reference phasor for the horizontal axis are more convenient to use as follows:

From phasor diagram

$$V(p + jq) + IR + jIX = E \tag{3.4}$$

After putting $r = \frac{IR}{E}$ and $x = \frac{IR}{E}$

$$\left(\frac{Vp}{E} + r\right)^2 + \left(\frac{Vq}{E} + x\right)^2 = 1 \tag{3.5}$$

From equation (3.5) $\left(\frac{Vp}{E} + \frac{IR}{E}\right)^2 + \left(\frac{Vq}{E} + \frac{IX}{E}\right)^2 = 1$

After solving equation (3.5)

Let <u>Effective resistance from transformer to load</u> = R (3.6)

Effective reactances from transformer to load = X

By substituting R= ax and solving for I

$$I = \frac{-\left(\frac{V}{E}\right)(ap + q) \pm \sqrt{1 + a^2 - \left(\frac{V}{E}\right)^2 (p - aq)^2}}{\left(\frac{X}{E}\right)(1 + a^2)}$$

For zero power-factor current:

$$Ic0 = \frac{-\frac{V}{E} \pm \sqrt{1+a^2 - \left(\frac{V}{E}\right)^2 a^2}}{\frac{x}{E}\left(1+a^2\right)}$$

These equations may be used to calculate the circuit performance for any given application.

3.2.Determination of Circulating Current

The magnitude of circulating current through parallel-connected transformers is proportional to the difference in the no-load output voltages divided by the total impedance of the loop through which the current flows. For example, for two units in parallel, the circulating current is

$$Ic = \left(\frac{E_A - E_B}{Z_{loop}}\right) \quad (3.7)$$

Where E_A and E_B are the no-load transformer voltages.

The phase angle (θ) of the circulating current with reference to the transformer no-load voltages is determined by R_{loop} and X_{loop} are the total resistance and reactance respectively around the loop.

A positive sign is used for the values of both cos θ and sin θ.

The approximate value of current through each of the two transformers may be determined from the following:

For unit A:

$$I_{Total} = \sqrt{\left(I_L \cos\alpha + I_C \cos\theta\right)^2 + \left(I_L \sin\alpha + I_C \sin\theta\right)^2} \quad (3.8)$$

For unit B:

$$I_{Total} = \sqrt{\left(I_L \cos\alpha - I_C \cos\theta\right)^2 + \left(I_L \sin\alpha - I_C \sin\theta\right)^2} \quad (3.9)$$

Where I_L = load current, I_C = circulating current, α = load-current phase angle, and θ= circulating-current phase angle.

3.3. Hold Voltage (No Circulating Current):

In the power circuit (see Fig 3)

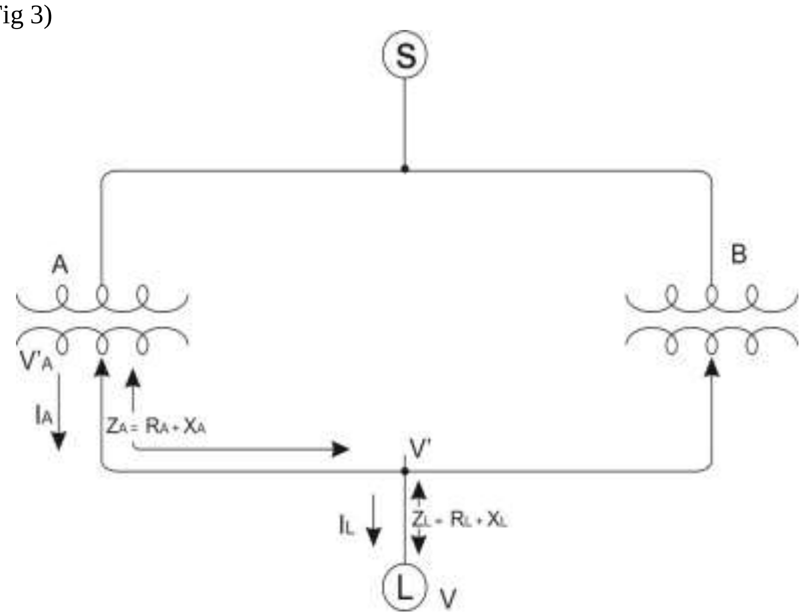

Figure 3. parallel connection of two transformers

$V_A' = V+I_AZ_A+I_LZ_L$ (3.10)
$I_L = NI_A$ (3.11)
$V_A' = V +I_A (Z_A+NZ_L)$ (3.12)
Assume V_A' is in phase with V.
Then,
$V_A'= V + I_A (R_A+NR_L) \cos \alpha + I_A (X_A+NX_L) \sin \alpha$ (3.13)
In the line-drop compensator circuit,
$V_A' = VR_A+I_AR_C +I_A X_C$ (3.14)
Assume V_A' is in phase with VR_A, then
$V_A' = VR_A + I_AR_C \cos \alpha + I_AX_C \sin \alpha$ (3.15)
Equating equations (3.15) and (3.12)
$VR_A + I_AR_C \cos \alpha + I_AX_C \sin \alpha = V + I_A (R_A + NR_L) \cos \alpha + I_A (X_A + NX_L) \sin\alpha$ (3.16)
To hold correct voltage
$V = VR_A$ (3.17)
From above equations and basic relationships
$I_A (R_A + NR_L - R_C) \cos \alpha + I_A (X_A + NX_L - X_C) \sin \alpha = 0$ (3.18)
$R \cos \alpha + X \sin \alpha = 0$ (3.19)

3.3.2 To Detect Circulating Current:

First assume zero circulating current and let V' = voltage at the paralleling point, then
$V' = I_A Z_{C(A)} - I_AZ_A + VR_A$ (3.20)
$V' = I_B Z_{C(B)} - I_BZ_B + VR_B$ (3.21)
$VR_A - VR_B = I_C (Z_B - Z_{C(B)})+ I_C (Z_A - Z_{C(A)})$ (3.22)
To detect circulating current I_C $VR_A - VR_B$ must equal or exceed the bandwidth BW in magnitude.
$BW = I_C (Z_B - Z_{C(B)}) + I_C(Z_A - Z_{C(A)})$ (3.23)

$$BW = I_C\left(Z_A - Z_{C(A)}\right)\left(1+\frac{I_A}{I_B}\right)$$

From definition of symbol N

$$N = \frac{I_A - I_B}{I_A} \quad \text{Or} \quad \frac{1}{1+\frac{I_A}{I_B}} = \frac{N-1}{N} \qquad (3.24)$$

$$BW\frac{N-1}{N} = I_C(X_A - X_C)\sin\theta + I_C\left(R_A - R_C\right)\cos\theta \qquad (3.25)$$

Solve equations (3.25) and (3.21) for Rc and Xc

$$Rc = R_A - \left[\frac{BW\frac{N-1}{N} + I_c N\left(R_L \cot\alpha + X_l\right)\sin\theta}{I_c\left(\cos\theta - \cot\alpha\sin\theta\right)}\right]$$

$$Xc = X_A - \left[\frac{BW \frac{N-1}{N} + I_c N(R_L + X_L \tan\alpha)\cos\theta}{I_c(\sin\theta - \tan\alpha\cos\theta)} \right]$$

3.4. Load Voltage Variation:

It is determined the voltage V for any load-current power factor.

$$V = -I_A R\cos\alpha - I_A X\sin\alpha + \sqrt{1-(I_A X\cos\alpha - I_A R\sin\alpha)^2} \quad (3.26)$$

If the voltage is being calculated for full load, I_A = 1.0 on a per-unit basis, the equation then reduces to

$$V = -R\cos\alpha - X\sin\alpha + \sqrt{1-(X\cos\alpha - R\sin\alpha)^2}$$

R and X are the total effective resistance and reactance respectively as shown by
$R = R_A + NR_L - R_C$
$X = X_A + NX_L - X_C$
α is the power-factor angle of the load.
There are a few advantages using Fuzzy logic controller in Power System

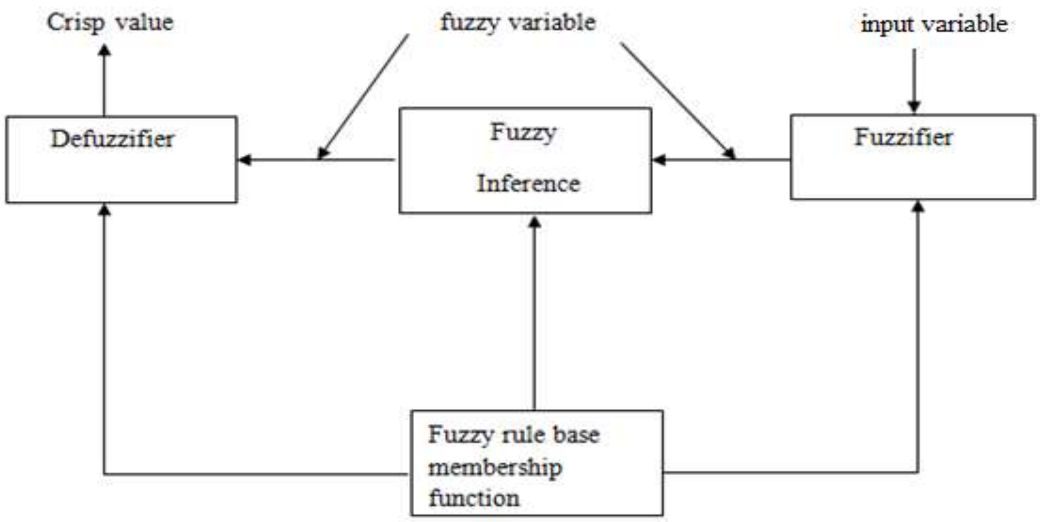

Figure 4 .Structure of fuzzy logic controller

a) Fuzzy logic is based on natural language and is conceptually easy to understand.
b) Fuzzy logic is tolerant of imprecise data and can handle ambiguity.
c) Fuzzy logic can be built on top of the experience of experts or can be implemented with other techniques.
d) Fuzzy logic can resolve conflicting objectives.
e) Fuzzy logic is flexible and is relatively easy to implement.

A FLC is a kind of a state variable controller governed by a family of rules and a fuzzy inference mechanism. The FLC algorithm can be implemented using heuristic strategies, defined by linguistically described statements. The fuzzy logic control algorithm reflects the mechanism of control implemented by people, without using any formalized knowledge about the controlled object in the form of mathematical models, and without an analytical description of the control algorithm. The main FLC processes are fuzzification, rules definition, inference mechanism and defuzzification. Fuzzification is the process of transferring the crisp input variables to corresponding fuzzy variables.

3.5. Fuzzy Logic controller

MATLAB's Fuzzy Logic Toolbox and Simpower system are used to simulate and design the Fuzzy logic based automatic voltage control relay.

Figure 5. Shows the schematic diagram of fuzzy logic based AVC relay. This relay consist 4-input and 1-output, which is low voltage side of OLTC transformer voltage (V), Phase angle of the current through the OLTC transformer.

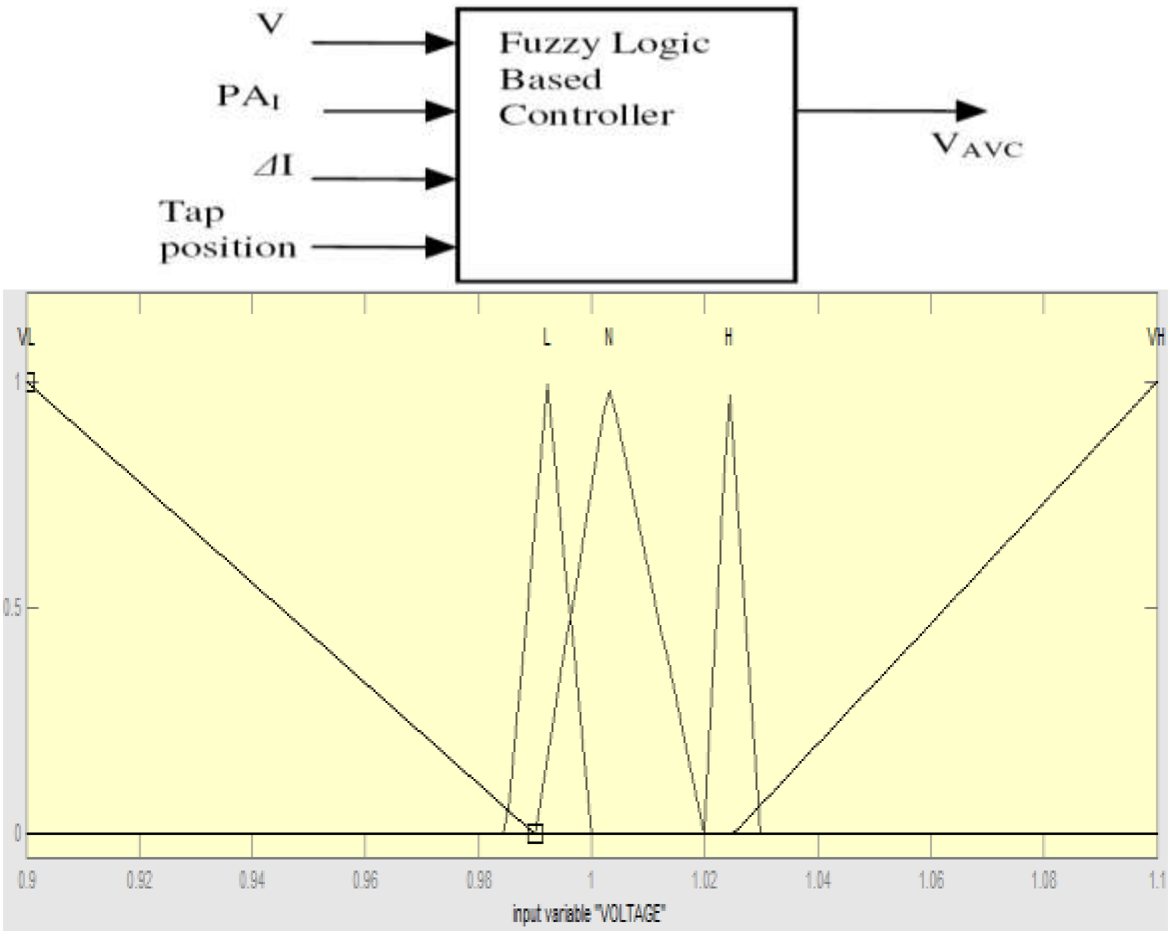

Figure.5. voltage at secondary side of OLTC transformer

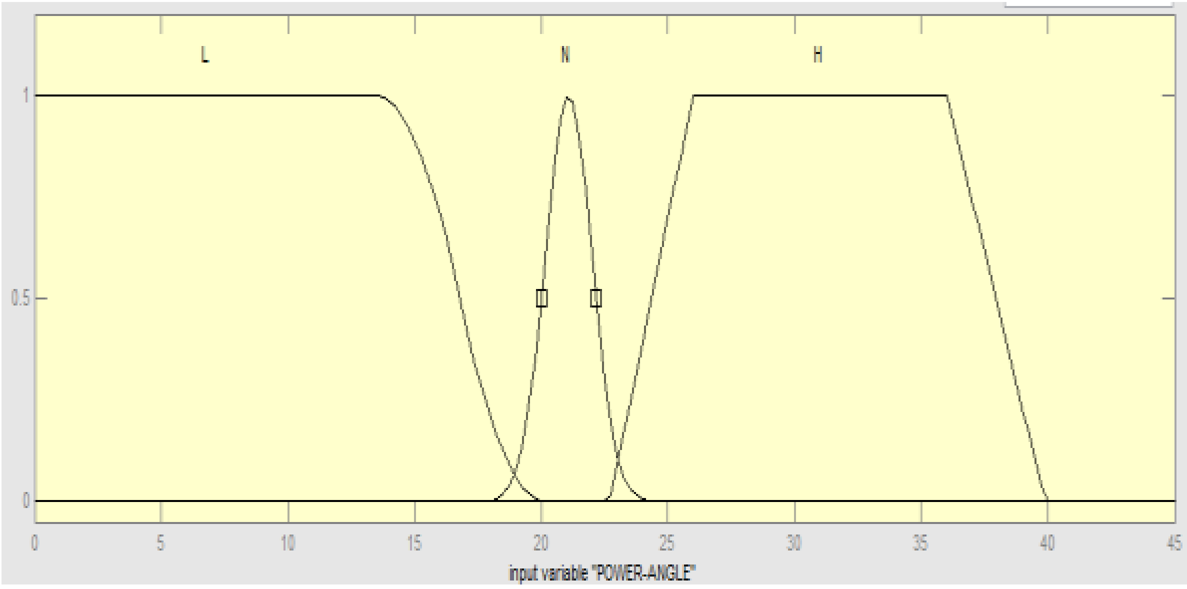

Figure.6. power angle of OLTC transformer

4. Simulation Diagram of Parallel Condition

Figure.6. shows the simulation diagram of 33/11KV distribution network. Here 33KV programmable voltage source is taken and 100 MVA RL series branch is connected. Two OLTC Regulating transformers are connected in parallel between Bus B1 and Bus B2. At the second end of Bus B2 three types of systems are connected namely system 1 which contains distribution generation, system 2 contains the load at different feeder and system 3 contains variable load.

Here all measurements are taken in the measurement block shown in fig 5.1. Here all the parameters of load are explaining in further systems.

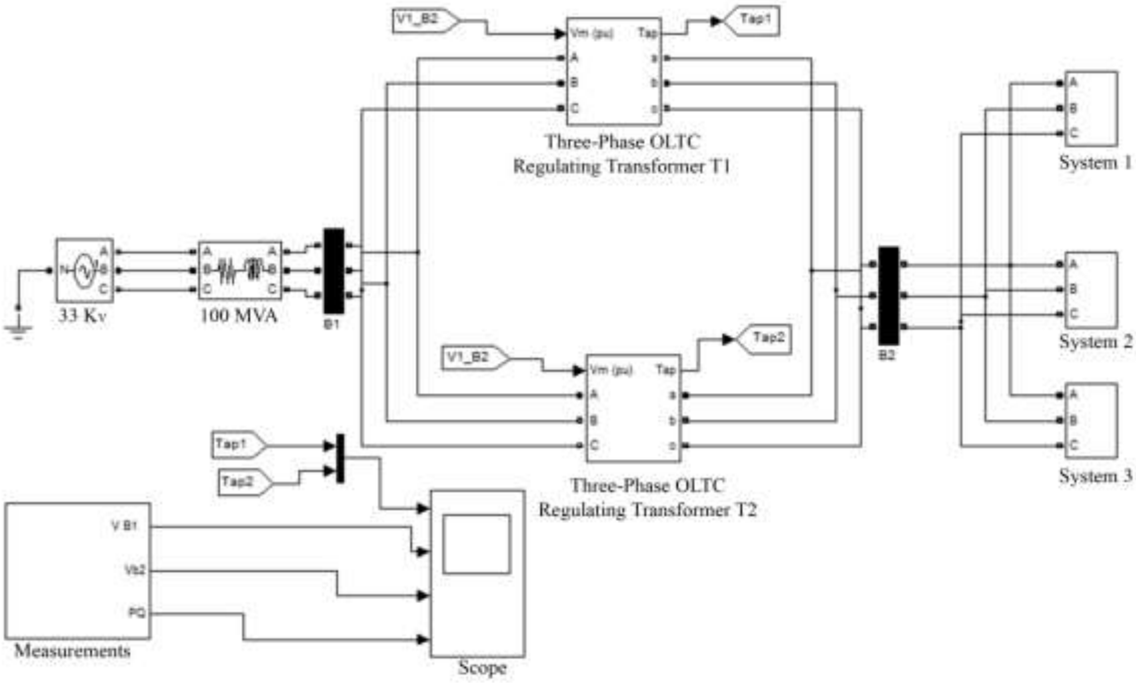

Figure.7. Simulation Diagram of parallel transformer

Figure.7.1. simulation diagram of system 1

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