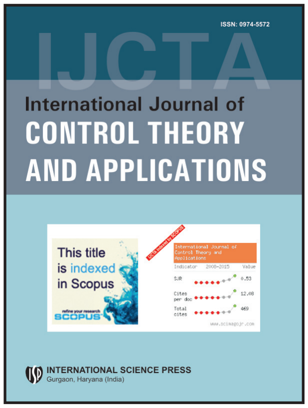

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FLC based AVC Relay with Newton Raphson Load Flow for Voltage Control in Distribution Network

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Abstract: On Load Tap Changer (OLTC) Transformers controlled by Automatic Voltage Control (AVC) relays are mostly used to maintain the voltage magnitude of distribution networks within statutory limits. Conventional AVC relay usually equipped with compounding whose settings are chosen in such a way to compensate for the voltage drop along the feeder(s) emanating from source substation. This paper presents an attempt to design a Fuzzy Logic Controller (FLC) based AVC relay with Newton Raphson (NR) load flow. The control system for the proposed AVC relay is simulated using fuzzy logic (FL) and NR program, which is written in MATLAB. In this paper, the structure of the proposed FL controller-based AVC relay with NR load flow is presented and its results that show its performance with distributed/embedded generation (DG/EG) in distribution network is discussed.

Keywords**:** Power Transformer, On-load Tap Changer Transformers, Distribution Systems, Automatic Voltage Control Relay.

1. INTRODUCTION

On Load Tap Changer (OLTC) Transformers which are controlled by Automatic Voltage Control (AVC) relays are mostly used in maintaining the voltage magnitude of a distribution network within statutory limits. Traditional AVC relays are usually equipped with compounding to compensate for the voltage drop in the distribution network [1]. Compounding should also allow effective operation of transformers connected in parallel. It has been reported that the presence of DG/EG in a distribution system causes the sending end voltage measured by conventional AVC relay to be shifted upwards or downwards compared with the absence of DG/EG [2].This situation leads to an improper voltage control of the distribution network. Apart from that, the currently available AVC relays requires many electrical measurements as an input for its operation. This paper presents an attempt to design an AVC relay based on the application of Fuzzy Logic (FL) with Newton Raphson (NR) load flow. The structures of the proposed FLC-based AVC relay model with NR load flow is presented. The test results which show its performance in a distribution network connected with DG/EG are also presented and discussed.

2. PRINCIPAL OF AUTOMATIC VOLTAGE CONTROL RELAY

The increasing use of DG/EG due to its high efficiency and low environmental impact is the key factor for transforming the traditional power grid to smart grid in the future. The smart grid uses intelligent devices and a digital communication in power system to enhance the performance of distribution grids. Therefore, the OLTC voltage control method may need to be changed in the future as the control needs to be more flexible and smarter [3, 4]. Figure 1 shows the various basic blocks of an AVC relay.

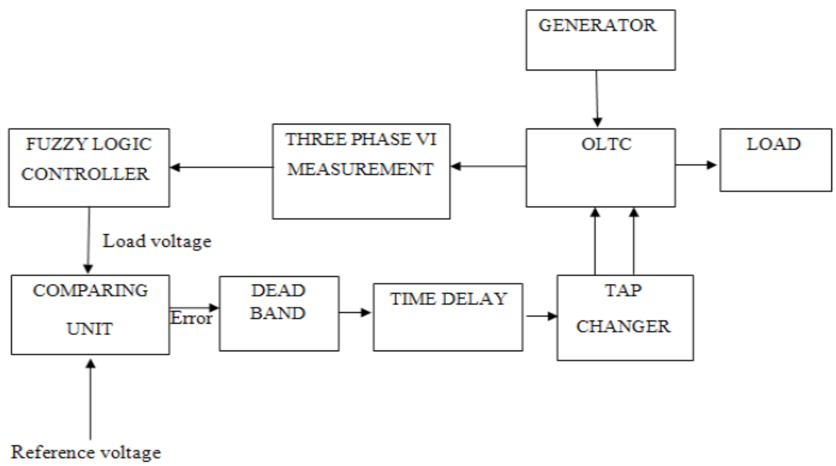

Figure 1: Block diagram of an AVC relay

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. 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 we can control the AVC relay:

(i) **Negative Reactance Compensation:** The negative reactance compounding (NRC) method helps to maintain similar tap positions for paralleled transformers by changing the polarity of reactance of LDC setting – X_{LDC} [5]. The following formulas show the relationship between LDC settings and negative reactance compounding (NRC) setting:

$$Z_{NRC} = R_{LDC} + jX_{LDC} \tag{1}$$

$$Z_{NRC} = R_{LDC} - jX_{LDC} \tag{2}$$

The operating principle of NRC is illustrated in Figure 2. Based on the phasor diagram shown in Figure 2, transformer T_1 has much higher tap position compared to transformer T_2. Due to the difference in tap position, a circulating current will flow between transformer T1 and transformer T2. The circulating current causes current I_{T1} to be shifted in clockwise direction and current I_{T2} in anti-clockwise direction. Both current I_{T1} and I_{T2} which passes through the ZNRC setting create a voltage drop $I_T \cdot Z_{NRC}$. The AVC relay uses this voltage drop to determine the proper tap position. Since the voltage at transformer T1 is higher than the target voltage therefore the AVC relay initiates a tap down operation. Similarly the AVC relay of transformer T2 initiates a tap up operation. The action stops with a similar tap position of both the parallel transformers when the circulating current is eliminated and target voltage is achieved.

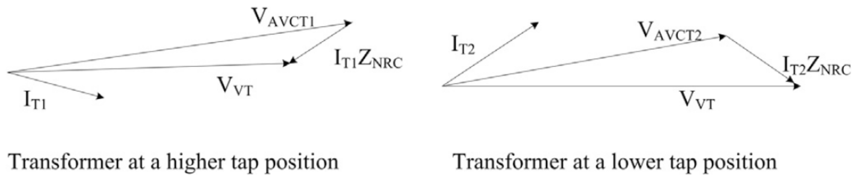

Figure 2: Operating principle of NRC [6]

The advantage of NRC scheme is that it can operate with transformers at different positions in the networks and it does not need to be identical anymore due to the independent action of each transformer. However, the NRC fails to operate satisfactorily when the power factor changes from a set point. Integration of irregular DG/EG into the network effects the NRC operation. Apart from that, negative value of XLDC setting could cause poor performance of LDC. An increased value of RLDC is needed in order to maintain the performance of LDC.

(ii) **Line Drop Compensation:** The aim of line-drop compensation is to keep the voltage constant, not at the local bus bar on the transformer secondary, but at some remote load center. Normal practice is to sense the load current (local to the transformer) and from this to simulate the voltage drop in the line to the remote load center. Modern voltage-control relays include line-drop compensation as standard.

A. On-Load Tap Changer Transformer

OLTC consist of two fixed windings and a third tap winding (regulation winding) connected in series with either winding 1 or winding 2. A +30° or –30° phase shift is introduced when winding 1 or winding 2 are connected in delta. In automatic mode voltage regulator on and the signal applied at the V_m inputs is monitored and the voltage regulator asked for tap change. The three-phase two-winding transformer or autotransformer uses an on-load tap changer (OLTC) for regulating voltage on a transmission or distribution system. Controlling voltage on a transmission system will affect primarily flow of reactive power, which, in turn, will affect the power transfer limits. Although the regulating transformer does not provide as much flexibility and speed as power-electronics based FACTS, it can be considered as a basic power flow controller.

B. Fuzzy Logic Controller

A fuzzy logic system performs certain non-linear mapping of its inputs into its outputs. Fuzzy logic systems are made simpler and faster by using simple “IF-THEN” relations. They reduced the design development cycle, simplify design complexity, improve control performance, simplify implementation and reduced the hardware cost. Apart from that, fuzzy rules are more expressive than crisp values. Figure 3 shows the schematic diagram of FL controller-based AVC relay. MATLab software is used to simulate the control system. The voltage (V) at the point of control is determined by both the source voltage (E) and the voltage drop (ΔV) along the feeder. The voltage drop along a feeder is influenced by various factors, such as line resistor (R) and reactance (X), reactive power flow (Q) and real power flow (P).

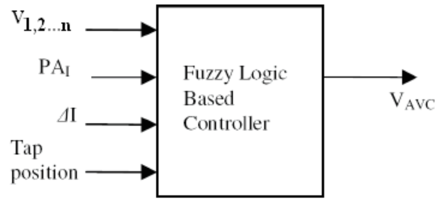

Figure 3: Fuzzy logic based AVC relay

The designed fuzzy logic control system uses Mamdani's Fuzzy Interference System (FIS), which is a linguistic model that describes the system by means of linguistic if-then rules with fuzzy proposition in the antecedent as well as in the consequent.

Fuzzy Membership Function

- Secondary voltage of the OLTC transformer: very high (VH), high (H), normal (N), low (L), very low (LV)
- Phase angle of current through the OLTC transformer: high (H), normal (N), low (L)
- Change of current: negative (N), zero (Z), positive (P)
- Tap position: low (L), normal (N), high (H)
- AVC relay voltage: high (H), normal (N), low (L)

Fuzzy Control Rules

- If voltage is very low, then AVC relay voltage is low.
- If voltage is low, tap position is normal and power angle is normal, then AVC relay voltage is normal.
- If voltage is low, tap position is low and power angle is normal, then AVC relay voltage is low.
- If voltage is normal and power angle is low, then AVC relay voltage is low.
- If voltage is normal and power angle is normal, then AVC relay voltage is normal.
- If voltage is normal and power angle is high, then AVC relay voltage is low.
- If voltage is high, tap position is normal and power angle is normal, then AVC relay voltage is normal.
- If voltage is high, tap position is high, then AVC relay voltage is high.
- If voltage is very high, then AVC relay voltage is high.
- If voltage is normal and power angle is low, then AVC relay voltage is normal.
- If voltage is normal and power angle is normal, then AVC relay voltage is normal.
- If voltage is normal and power angle is high, then AVC relay voltage is high.

Figure 4 shows the structure of fuzzy logic controller. 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.

C. Newton Raphson Load Flow Computation

The NR load flow equation as below is used for PQ busbar.

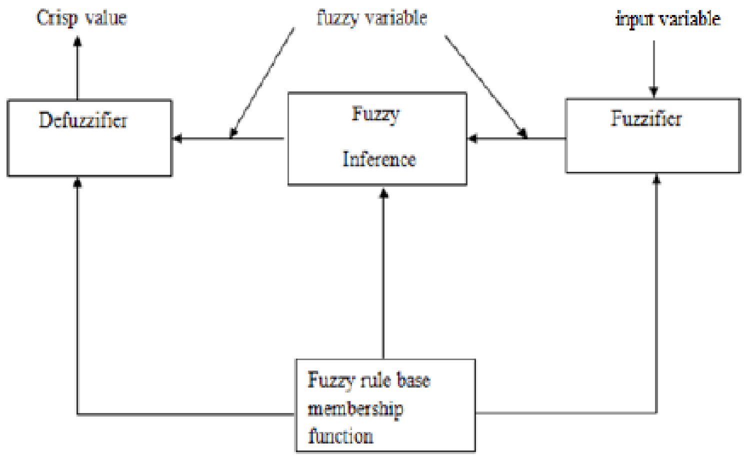

Figure 4: Structure of fuzzy logic controller

$$\Delta P_i = P_i^{sp} - V_i \sum_{k=1}^{n} V_k (G_{ik} \cos \theta_{ik} + B_{ik} \sin \theta_{ik}) = 0 \tag{3}$$

$$\Delta Q_i = Q_i^{sp} - V_i \sum_{k=1}^{n} V_k (G_{ik} \sin \theta_{ik} - B_{ik} \cos \theta_{ik}) = 0 \tag{4}$$

where, ΔP_i and ΔQ_i are called the active and reactive power mismatches at busbar *i*.

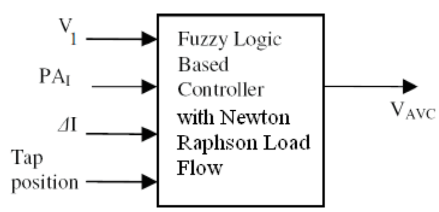

Figure 5: Fuzzy logic based AVC relay incorporating NR load flow algorithm

3. CASE STUDY

The 132/11 kV distribution network model connected with 2.5 MW DG/EG as shown in Figure 6 is simulated using PSCAD/EMTDC software.

The distribution system is simulated under various conditions as stated in Table 1 to check the performance of the FLC based AVC relay with NR load flow.

Table 1
Summary of simulated cases used for testing the FLC-based AVC relay with Newton Raphson

Time (s)	*Load connected (MW)*			
	L1	*L2*	*L3*	*L4*
0 – 5	0.50	1.00	1.50	2.00
6 – 10	0.50	1.00	1.50	2.50
11- 15	0.50	1.00	1.50	3.00
15 -20	0.50	1.00	1.50	3.50
20 - 25	0.50	1.00	1.50	4.00

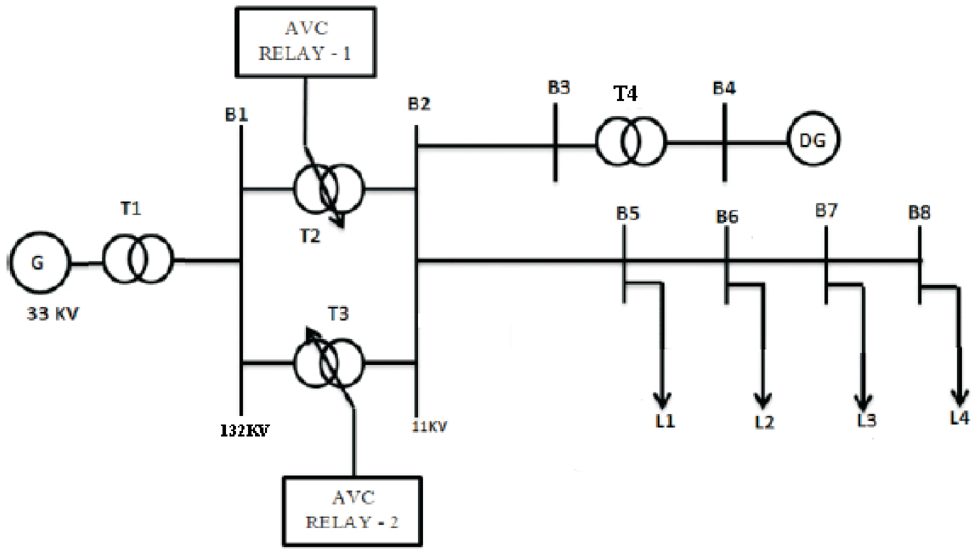

Figure 6: Single line diagram of distribution network with DG/EG

4. SIMULATION RESULTS

Figure 7 shows the voltages at buses where loads L1, L2, L3 and L4 are connected in the distribution network without OLTC operation. These voltages are obtained through PSCAD simulation. It is found that the voltage level at the end of the feeder (point of L4 connection) is below the threshold value of 10.45 kV.

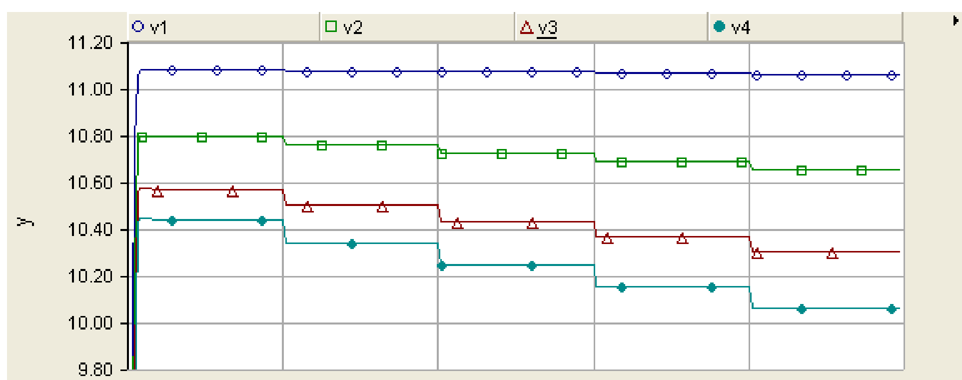

Figure 7: Bus voltages from simulation

The value of voltage at the end of the feeder (point of L4 connection) is compared with the value obtained through NR computation. Figure 8 shows both voltage values obtained through simulation and NR load flow computation.

It is noted that the voltage value obtained through NR load flow is quite similar to the simulation values. Figure 9 shows the AVC relay voltage in per-unit value using the voltage value obtained through simulation.

Figure 10 shows the improved feeder voltage profile using AVC relay voltage for voltage value at the end of the feeder obtained through simulation.

It is observed that the voltage at the point of control (point of L4 connection) is improved to an acceptable level with tap operation using AVC relay voltage by referring to voltage value obtained through simulation. Figure 11 shows the AVC relay voltage in per-unit value using the voltage value obtained through NR load flow computation.

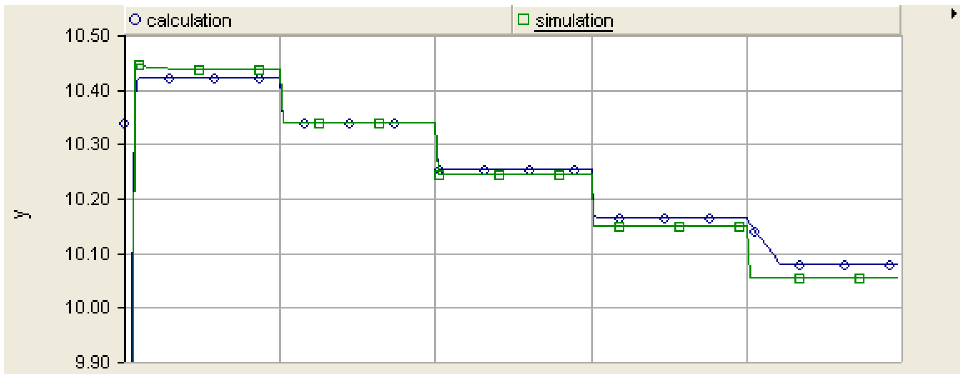

Figure 8: Voltage level at the end of the feeder obtained through simulation and NR load flow

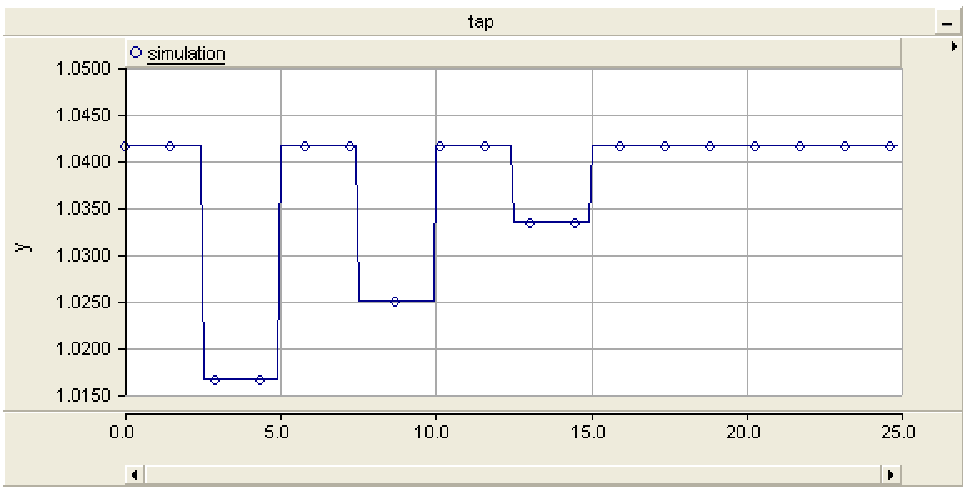

Figure 9: AVC relay voltage (in per-unit value) for voltage value obtained through simulation

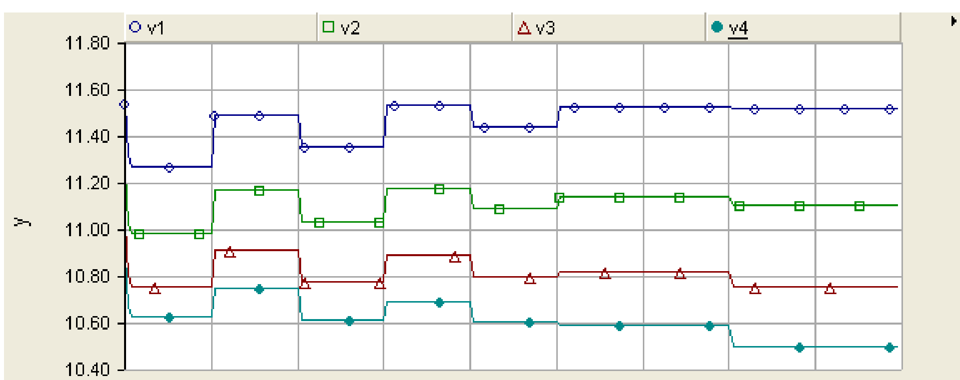

Figure 10: Feeder voltage profile with tap operation using AVC relay voltage by referring to voltage value obtained through simulation

Figure 12 shows the improved feeder voltage profile using AVC relay voltage for voltage value at the end of the feeder obtained through NR load flow computation.

It is observed that the voltage at the point of control (point of L4 connection) is improved to an acceptable level with tap operation using AVC relay voltage by referring to voltage value obtained through NR load flow computation. The finding shows that the FLC based AVC relay with NR load flow computation could help to improve the voltage level at the point of control to be within acceptable limits.

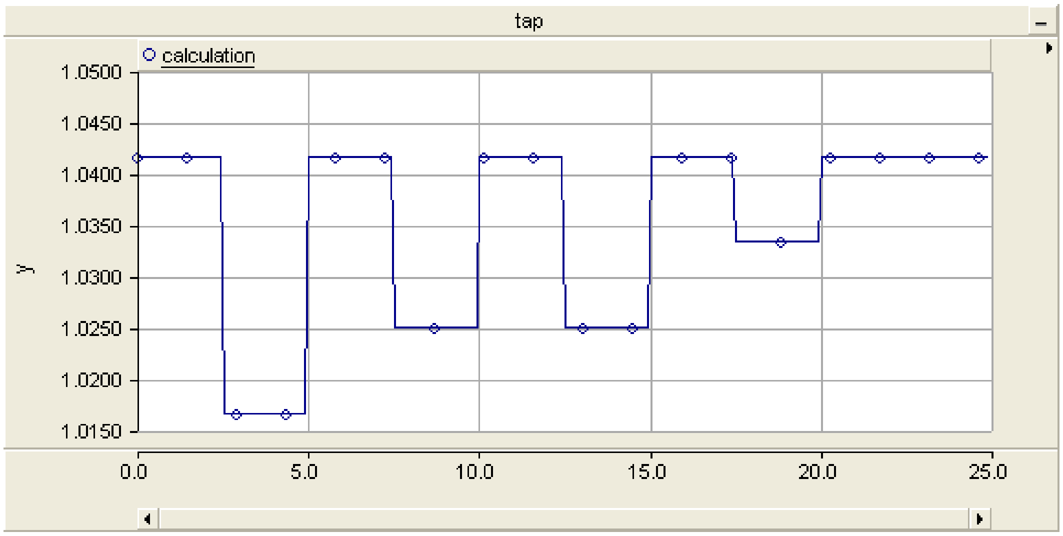

Figure 11: AVC relay voltage (in per-unit value) for voltage value obtained through NR load flow computation

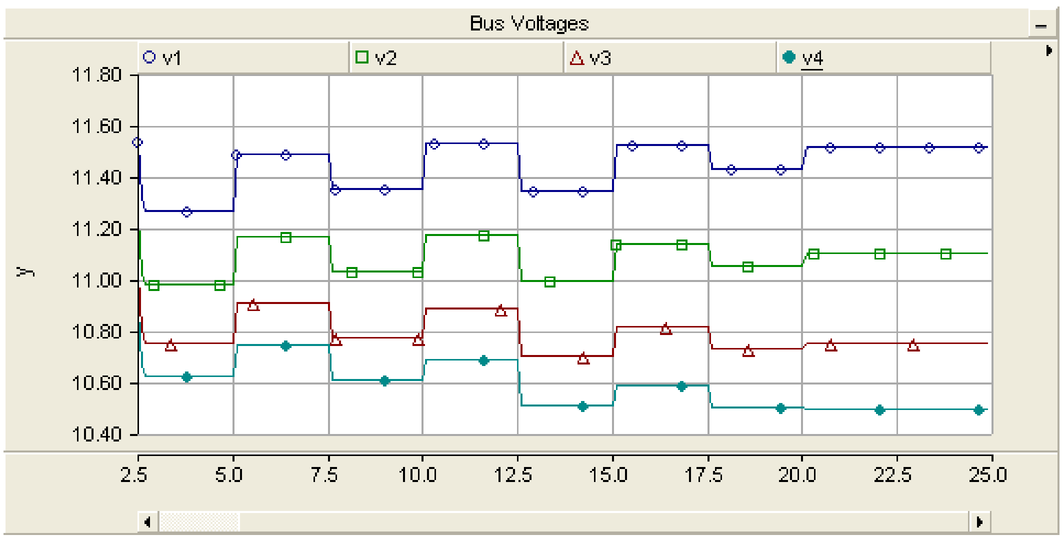

Figure 12: Feeder voltage profile with tap operation using AVC relay voltage by referring to voltage value obtained through NR load flow computation

5. CONCLUSION

The use of NR load flow algorithm in estimating the voltage of FLC-based AVC relay was investigated in this paper. The results obtained were found to be very encouraging. It has been found that the proposed FLC-based AVC relay with NR load flow has the ability to properly control voltage magnitude of distribution network as load changes.. The advantage of the FLC-based AVC relay with NR load flow is that it requires reduced electrical measurements for its operation which leads to reduced distribution cost.

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