New control scheme of on-load tap changer for voltage regulation in active distribution systems using Fuzzy logic

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Abstract. This research presents a new voltage regulation philosophy that enhances the voltage magnitude in a power distribution network where distributed generation (DG) is prevalent. Voltage regulation in power distribution networks relies heavily on the On-Load Tap-Changer (OLTC) installed in power transformers. Since it was designed for networks without DG, the OLTC's current voltage regulation scheme uses a fixed reference voltage and hence cannot regulate voltage in a distribution network. Therefore, the proposed novel system-based Fuzzy logic will compute a new set point voltage that the OLTC must follow to mitigate the undesirable DG impact on the voltage profile. The suggested system is evaluated on Morocco's MATLAB/Simulink-built 20kV distribution network.

1 Introduction

The modern world's increasing need for power, as well as the search for the best solution to environmental problems and considering the high price of fossil fuels, has prompted the use of new energy sources that are renewable, also known as distributed generation (DG). Because they are positioned closer to the consumers, renewable energy sources have the advantage of lowering transmission line losses and supporting the distribution system's voltage level **[1].**

Solar energy (photovoltaic) and wind energy are two examples of renewable energy sources utilized in Morocco nowadays **[2]**. The conventional distribution network is passive and has a one-way power flow, but with the connection of the DG to the network, the direction of the power flow is changed, can be either from loads to the power grid or vice versa, and therefore, the network is called an active distribution network. The change direction of power flow takes place when DG output active power is bigger than the network local load.

Interference of reverse power flow with conventional voltage control components on the power distribution system produces an increase in voltage magnitude at the point of connection of distributed generation and a drop at the end of feeders without DG **[3].** A passive electrical distribution network without distributed generation will have a voltage magnitude that decreases from the substation busbar to the end of the feeder due to transmission line losses, with the assumption that the highest voltage magnitude exists in the secondary of a power transformer in a substation **[4].**

Because the on-load tap changer is positioned in the substation and the voltage magnitude drops from the substation busbar to the feeder end busbar, all of this will allow the OLTC to efficiently regulate the voltage. By keeping the substation busbar voltage at a little greater magnitude than the nominal voltage, the voltage throughout the distribution system can be maintained above the lowest allowable limit **[5].**

Under extreme conditions of power flow reversal. The substation busbar may cease to be the highest voltage point in the distribution system and be replaced by the voltage at the distributed generator connection node, the OLTC would not be able to provide a better voltage control in this case because its voltage regulation scheme expects that the substation busbar with the maximum voltage level is still available **[6],** these make the current OLTC voltage regulation scheme inappropriate for voltage control when DGs are incorporated into the power distribution network

There are already many techniques found in the literature to control the voltage in an active distribution network.

[7] Presents a fuzzy-based control of the OLTC. The OLTC takes into account the transformer's secondary voltage and the target voltage, as well as the difference between the measured and nominal transformation ratio. The tap changer is controlled by the fuzzy logic controller, which adjusts the transformer's primary voltage. nevertheless, The DG impacts on the voltage have not been taken into account in this proposed strategy.

[8] Voltage/reactive power sensitivity analysis is employed in the proposed control technique to minimise

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the total system deviation. A power flow analysis is carried out, and each DG acts as a local control agent to calculate its voltage deviation and the available reactive power for lowering it, as well as to monitor the load and its power consumption.

[9] Proposes an adaptive fuzzy reference that allows DGs to function at different power factors, allowing them to provide decentralized voltage control. The main drawback of this system is that it ignores the coordination between the DG and the OLTC, Furthermore, because reactive power support is constantly dependent on active power, the DG cannot regulate the voltage if the generated active power is insufficient.

[10] Another technique is presented, which divides the voltage control into three zones, with the OLTC regulating one zone and the second another zone, while the voltage regulator takes the second zone while the integrated generator with its reactive power capabilities regulates the last zone. However, the high ratio of R/X in the power distribution network does not allow the reactive power of the DG to effectively regulate the voltage.

A fuzzy voltage regulation control algorithm for the reference value of the OLTC is proposed in this study paper. With the suggested voltage regulation scheme, the standard OLTC function scheme will be modified in order to improve the voltage regulation process when DGs are present in the system. Instead of having one input from the substation busbar, the OLTC will have many measured inputs and pick between them the system's maximum and lowest voltages, rather than relying solely on the substation busbar. Then the fuzzy controller will determine the reference voltage.

The following is the structure of this paper. Section 2 explains the OLTC's voltage regulating method. Voltage regulation and distributed generators will be illustrated in section 3 via a fuzzy control system. MATLAB/SIMULINK simulation results and discussions are presented in sections 4 and 5, and a conclusion is made in section 6.

2 CONVENTIONAL VOLTAGE REGULATION SCHEME OF OLTC:

Voltage regulation in power distribution networks makes use of a wide variety of devices, among these the On-Load Tap Changer (OLTC) installed at the HV/MV transformer is the most commonly used for voltage regulation. They allow the voltage of the MV busbars to be modified as a result of variations in upstream voltage caused by changes in the loads. A typical on-load tap changer has 17 taps (8 up and 8 down) with a step size of 0.625%, i.e. ±5% of the voltage ratio can be changed with this device. The dynamic operation of the controller under load is illustrated in Figure **1 [11].**

Due to transitory fluctuations, while connecting or detaching large loads, an additional one-minute delay Δt1 is imposed on the initial tap change if the measured voltage is beyond the permissible range threshold. If more tap modifications are required after the initial one, the delay Δt2 can be lowered to 10s.

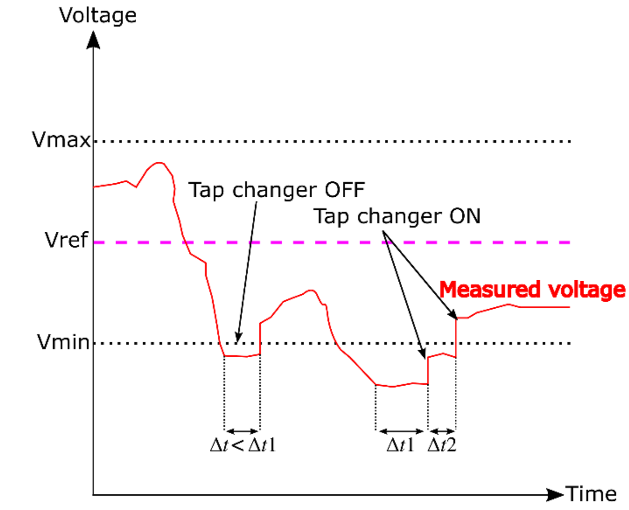

Fig. 1. OLTC under load variation.

The On-load tap changer permits the voltage to fall within a predetermined range surrounding the voltage setpoint:

$$Vmin \leq V \leq Vmax \tag{1}$$

$$Vmax = Vref + \frac{DB}{2} \tag{2}$$

$$Vmin = Vref - \frac{DB}{2} \tag{3}$$

Where the DB is the deadband and Vref voltage setpoint.

The operating principle of OLTC is shown in figure 2[12].

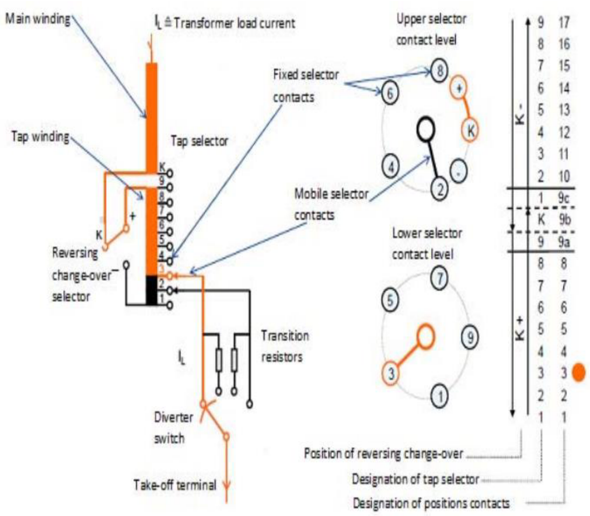

Fig. 2. The operating concept of OLTC

In most cases, the on-load tap changer's set point is determined by the voltage on the MV busbar. Figure 2 shows the operation of the OLTC while maintaining a constant voltage magnitude on the MV busbar, as illustrated. A voltage drop compensation (LDC) can also be used to connect the OLTC to the voltage at the feeder's end (LDC). Most OLTCS don't use the compounding function because it complicates things and can lead to unnecessary errors.

3 DISTRIBUTED GENERATORS AND VOLTAGE REGULATION:

A voltage drop will occur along the feeder's impedance as power is transmitted from the substation's busbar to the load busbars in a passive network, hence the MV busbar will still have the highest magnitude of voltage **[13].** An MV distribution network is illustrated using a simplified single network line diagram shown in Figure 3, Just for understanding the distribution power network has a single load connecting to it through a feeder of Resistance R_f and Reactance X_f, the active power demand of the load is denoted by PL, and the reactive power demand of the load is denoted by QL.

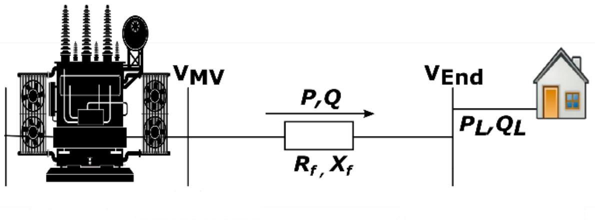

Fig. 3. Passive distribution network

The voltage drop along the line can be written by equation (1)

$$\Delta V = V_{MV} - V_{End} \quad (4)$$

$$\Delta V = \frac{R_f P_L + X_f Q_L}{V_{End}} + j\frac{X_f P_L - R_f Q_L}{V_{End}} \quad (5)$$

Equation (6) can be found by simplifying equation (5) due to the fact that the imaginary term is less significant than the real term

$$\Delta V \approx \frac{R_f P_L + X_f Q_L}{V_{End}} \quad (6)$$

In Figure 4, a distributed generator is linked to the distribution network. Voltage drop can be written in the following form:

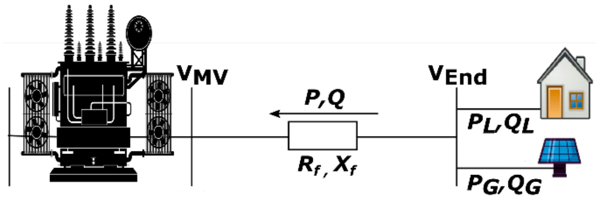

Fig. 4. Active distribution network.

$$\Delta V = V_{End} - V_{MV} \quad (7)$$

$$\Delta V \approx \frac{R_f(P_L - P_G) + X_f(Q_L - Q_G)}{V_G} \quad (8)$$

The voltage drop along the line is ΔV, in equation (8), where Rf is the line resistance and Xf is the line reactance, PG is the active power generated by the distributed generator, QG is the reactive power of the embedded generator, and PL and QL are the active and reactive powers of the load, respectively.

The reverse power becomes more aggravated when the DG active power (PG >> PL) thus the voltage rises above the statutory limits.

4 PROPOSED CONTROL SYSTEM:

The transformer's ratio is adjusted by the OLTC by adding or removing turns from zero turns in the case with the absence of voltage compensation to maximum turns in the case with the presence of maximum voltage compensation. Usually. The conventional OLTC scheme with a fixed secondary voltage magnitude setpoint is based on the assumption of voltage profile dropping from substation busbar to the load terminals; On the other hand, the incorporation of distributed generators changes this assumption and makes voltage regulation inappropriate with the conventional OLTC scheme. therefore, requires modifying the conventional OLTC scheme with a fixed setpoint to an adaptive one by using fuzzy logic inference system.

A fuzzy logic-based voltage regulation controller, which receives voltage magnitude measurements from all critical locations nodes on the power distribution network, and thus adapts the reference voltage set point of the OLTC, is proposed to overcome the current OLTC system's incapacity to manage voltage by integrating distributed generators into the electricity distribution network.

Distribution generation impacts the voltage magnitudes of the power distribution network, which means the fuzzy logic controller will adjust the OLTC's optimal voltage set point based on these changes to reduce overvoltage and undervoltage and to prevent tap hunting when the regulated voltage magnitude exceeds the allowable limit.

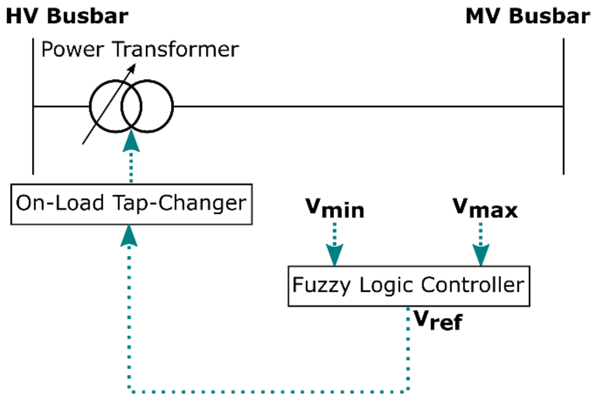

Fig. 5. New OLTC control system

For the fuzzy logic controller depicted in Figure 5 to work, two inputs are needed. Vmax and Vmin are the maximum and minimum voltage magnitudes, respectively. The controller's inputs are determined by the voltages on the secondary side of the power transformer, the voltages on the busbars to which dispersed generators are attached, and the voltages on the ends of feeders.

$$Vmax = \text{maximum } (V1, V2, \dots, Vi, \dots Vn) \quad (9)$$

$$Vmin = \text{minimum } (V1, V2, \dots, Vi, \dots Vn) \quad (10)$$

The 3 membership functions for Vmin and Vmax are shown in Figure 6**.** while figure 7 shows the output membership functions of the voltage step point of the OLTC.

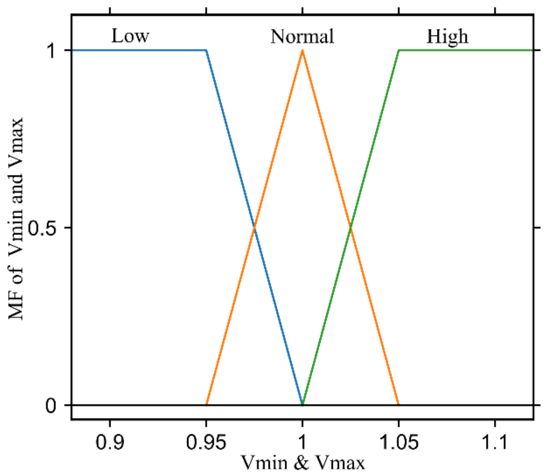

Fig. 6. Inputs membership functions of the fuzzy logic controller.

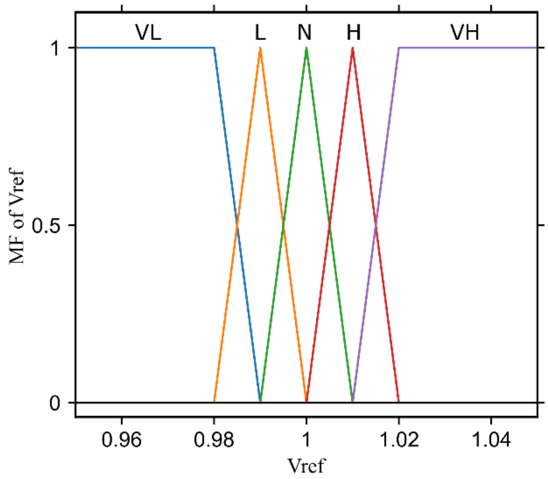

Fig. 7. Outputs membership functions of the fuzzy logic controller.

Where (VL, L, N, H, VH) are respectively very low, low, normal, high, and very high.

it can be read as follow:

- If Vmax is high and Vmin is Low then voltage reference is Low
- If Vmax is Normal and Vmin is Normal then voltage reference is Normal
- If Vmax is High and Vmin is High then step voltage reference is Very low

The fuzzy rule base is shown in **table 1**

Table 1. Presents the fuzzy rule base.

		Vmax		
Vmin		**Low**	**Normal**	**High**
	Low	VH	H	N
	Normal	H	N	L
	High	N	L	VL

5 SIMULATION RESULTS AND DISCUSSIONS:

The test network is a 13-busbar generic Moroccan MV distribution network with three radial feeders serving different loads. The single-line diagram of the network is shown in Figure 8.

The distribution feeders are connected to a 40 MVA OLTC power transformer with a nominal voltage of 63/20 kV. Feeders 1, 2 and 3 of the electrical network, as shown in the diagram, have 12 loads, respectively. It was estimated that the network's maximum load requirement would be 16 MW. The first feeder has one distributed generator linked at bus 1, and the third feeder also has also one connected at the feeder's end.

 https://doi.org/10.1051/itmconf/20224804001

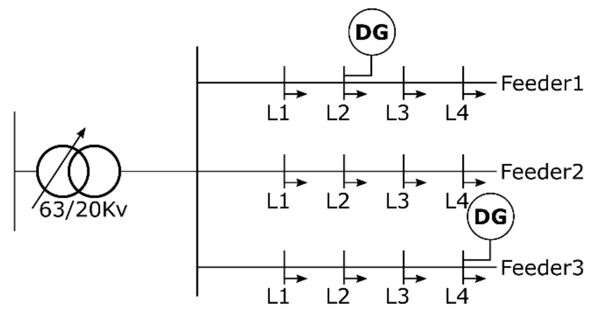

Fig. 8. The proposed Moroccan test network

Table 2 shows the genetic test system's specifications:

Table 2. Specifications of the proposed test network.

Parameter	Values
OLTC power transformer	40MVA 63/20KV 50HZ 17 taps
Network short circuit level	100MVA
Feeder	0.320+j0.119 ohm/km, feeder1=4km, feeder2=4km, feeder3=4km
Loads	Feeder1=4MW, Feeder=8MW, Feeder=4MW

5.1 First case: minimum load and maximum DG output power

In this scenario, each feeder has 4MW of load demand condition. The DG output power generated and absorbed at feeder 1 and feeder 3 is, respectively. 5MW/1.14MVAr and 10MW/2.28MVAr. The voltage of critical buses with conventional OLTC voltage regulation algorithm and after implementing the new OLTC control algorithm is shown in Fig 9 and fig 10 respectively.

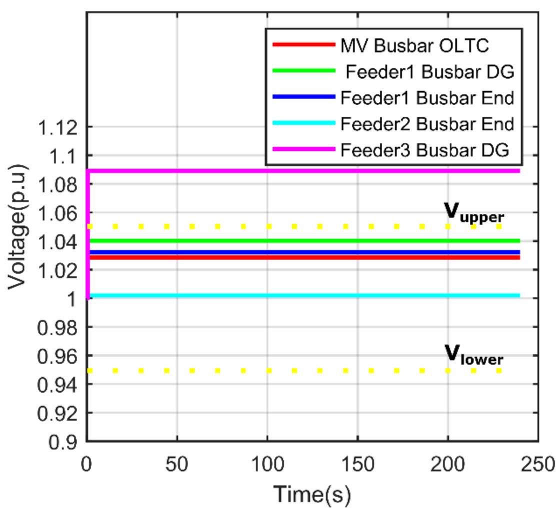

Fig. 9. voltage magnitude of the first case without the proposed controller.

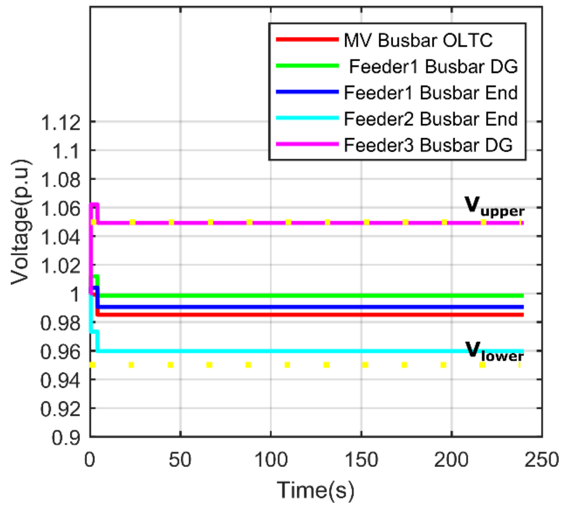

Fig. 10. voltage magnitude of the first case with the proposed controller.

From figure 9 the voltage magnitude at the end of feeder 3 is 1.09 which exceeds the upper limit. By implementing the proposed control algorithm set a new voltage reference Vref =0.985pu. Therefore, the voltage magnitude is set in a predefined limit as shown in figure 10.

5.2 Second case: Maximum load and minimum DG output power

In this scenario feeder1 and feeder3 have 4MW and the load at feeder 2 is increased from 4MW to 8MW. The DG output power generated and absorbed at feeder 1 and feeder 3 is reduced to 1MW/0.228MVAr and 1MW/0.228MVAr., respectively. The voltage of critical buses with conventional OLTC voltage regulation algorithm and after implementing the new OLTC control algorithm is shown in Figure 11 and figure 12 respectively.

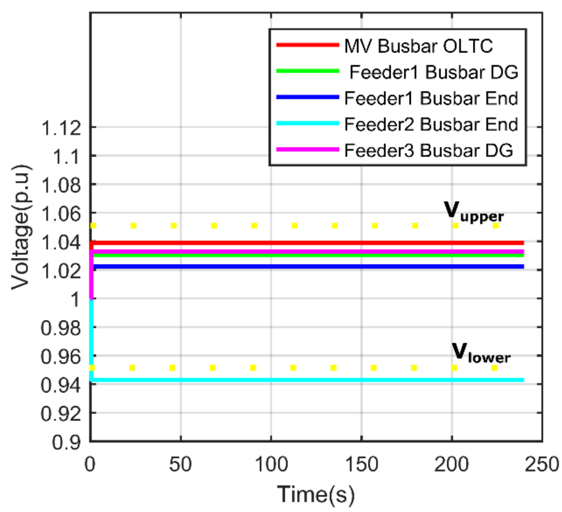

Fig. 11. voltage magnitude of the second case without the proposed controller.

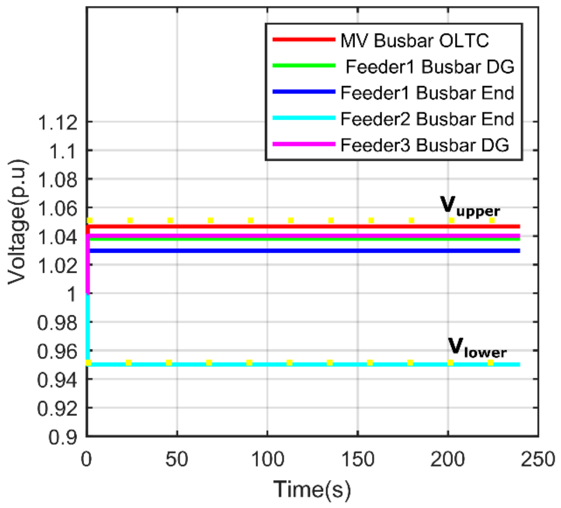

Fig. 12. voltage magnitude of the second case with the proposed controller.

From figure 11, the voltage magnitude at the end of feeder 2 is 1.04pu, which is below the lower limit. By implementing the proposed control algorithm, a new voltage reference is set Vref =1.05pu. Therefore, the voltage magnitude at the end of the feeder 2 is set in a predefined limit as shown in figure 12.

6 CONCLUSION:

Increasing the amount of dispersed generating connections necessitated the development of a fuzzy voltage control system, which is described in this study. The fuzzy logic-based control method introduced here replaces the traditional OLTC technique.

On the Moroccan distribution network, the voltage control system was put to the test. The results of the simulations show that the proposed voltage control method is able to overcome the voltage deviation caused by the substantial incorporation of distributed generators.

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