DESIGN OF ON LOAD TAP CHANGING TRANSFORMER (OLTC) TO INCREASE PHOTOVOLTAIC PENETRATION LEVEL IN LOW VOLTAGE DISTRIBUTION FEEDER

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Abstract

This paper investigates a method for regulating the voltage profile and reducing the voltage unbalance at low voltage (LV) residential feeders with single-phase rooftop photovoltaic (PV) installed randomly along with the feeders. The used algorithm considers the distribution transformers that have on-load tap changers (OLTC) and can automatically control the voltage to prevent voltage rise in the feeder. MATLAB-based simulation results demonstrate the effectiveness of the discussed approaches.

Keywords: *OLTC, rooftop PV, LV residential feeders, voltage profile, MATLAB platform.*

INTRODUCTION

Nowadays, most of the residential rooftop photovoltaic (PV) systems are single-phase units, and their integrations into the three-phase networks might also cause unbalance issues due to their random locations and ratings [1, 2]. For simplicity, a PV cell along with its converter is referred to as a PV system. The massive number of PVs in the network can change the direction of power flow and lead to voltage rise along the feeder [3].

A variety of studies have investigated how to regulate voltage profile in the presence of high PVs penetration in the feeders. The most common mode of voltage regulation in high voltage networks is the application of transformers with on-load tap changers (OLTC) [4]. However, transformers with OLTC are very expensive and are only limited to high-voltage networks. According to the author in reference [5], a traditional distribution transformer can be modified to act as a low voltage (LV) OLTC transformer by adopting semiconductor devices. In certain condition, LV distribution with OLTC can regulate the voltage profile in the network.

This paper aims to mitigate the use of OTLC in order to regulate voltage profile and reduce voltage unbalance in the LV feeder that has single-phase rooftop PVs along it which installed randomly with the range of 1-5kW.

The rest of the paper is arranged as follows. Section one describes briefly the use of OLTC in several studies, and the advantages and drawbacks that were raised through it. Section two explains in detail the proposed LV network with 1-5kW single-phase rooftop PVs along the three-phase feeder. The proposed network modeling and analysis is also developed in the MATLAB platform. Section three discusses the simulation of the proposed model in MATLAB by using an unbalanced sweep forward-backward load flow method for the analysis of the three-phase four-wire radial network under consideration. Section four concludes the proposed system, also provides the advantages of adjusting OLTC.

METHOD

As mentioned in the previous section, this section explains the detailed proposed network, its configuration, including its data to simulate in MATLAB, and the used model, which is the unbalanced sweep forward-backward load flow method for the analysis of the three-phase four-wire radial network.

Proposed Network

Based on reference [2], and the distribution construction standards [6], the proposed network data utilized in the simulation study, are provided in Table 1, and the random location and ratings of the PVs in the network are listed in Table 2, whereas the installed single-phase rooftop PVs along the feeder considered uniform 5kW.

Table 1. Technical parameter of proposed LV distribution network.

Transformer	11/0.380kV, 500kVA	$\Delta/Y_{grounded}$, X_{tr} =0.04pu
MV Feeder	Three-phase 11kV radial	z=1.08+j0.0302 Ω/km
LV Feeder	380V, 3-phase 4-wire	z=0.452+j0.270 Ω/km

Table 2. Location of the proposed LV distribution network.

Node	1	2	3	4	5	6	7	8	9	10
Phase A	5	5	5	5	5	5	5	5	5	5
Phase B	-	-	5	-	-	5	-	-	5	-
Phase C	-	-	-	5	-	5	-	-	5	5

The voltage profile along the LV feeder should be kept within the recommended limits of 95% and 110% of the nominal voltage [7]. By utilizing a transformer with OLTC, the turn ratio of the transformer is adjustable. Figure 1 illustrates the schematic diagram of a transformer with OLTC. Then assumed a constant primary voltage, the transformer secondary voltage can be increased or decreased such that the voltage all along the feeder is kept within the acceptable limits.

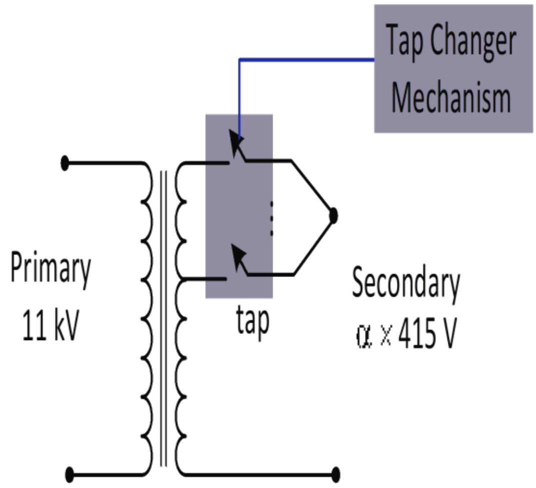


Figure 1. Schematic Diagram of transformer with OLTC

The system operation assumes that two voltage sensors are installed in the network one at the beginning of the feeder and one at the end of the feeder. Both of these voltage sensors are assumed to have data communication capability (using WiFi or ZigBee, etc.) to transfer the measured voltage to the master controller that is installed at the distribution transformer. We can adopt the communication model in reference.

We assumed that the 5kW single-phase rooftop PVs are located at all bus along the three-phase feeder. The objective is to observe the possibility to combine two different methods for regulating the voltage profile at low voltage residential feeders, whereas the tap changer of the transformer is automatically set as the single-phase rooftop PVs highly penetrated. It is assumed that proper voltage monitoring and transmitting devices are available throughout the feeders to provide data transfer among the controllers of the rooftop PV inverters. Figure 2 illustrates the step of adjusting OLTC in flowchart mode.

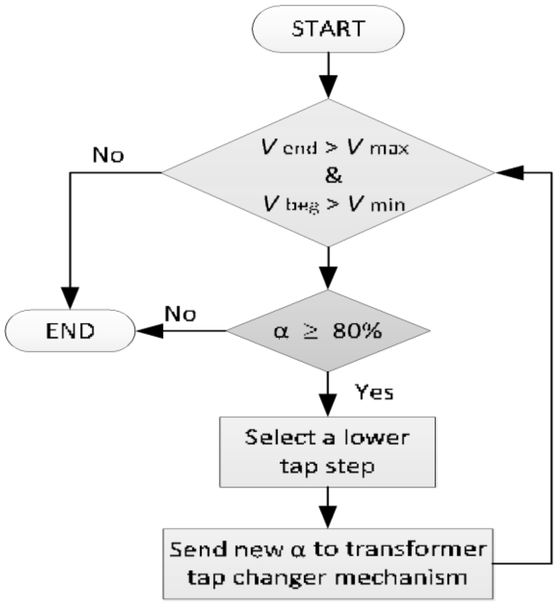


Figure 2. Flow chart of tap changer control algorithm [2].

Proposed Network Model

An unbalanced sweep forward-backward load flow [8] is considered and integrated into the developed model. The load flow calculates the bus voltages along the feeder. For this, first, modified Carson's equations [8] are utilized for the calculation of self and mutual impedance of the conductors in the 50 Hz system. The load flow model configurations and equations modeled in MATLAB are adopted from reference [2].

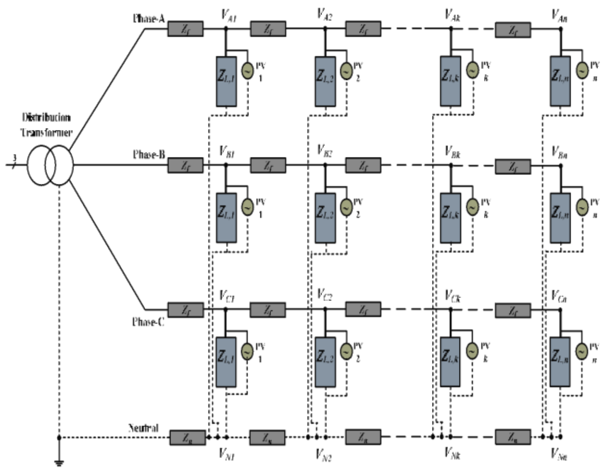


Figure 3. Single line diagram of proposed LV network with single-phase rooftop PVs [2].

Figure 3 illustrates the single-line diagram of the proposed three-phase unbalanced LV network with randomly located single-phase rooftop PVs. Figure 4 illustrates the data management flowchart for the adopted communication model. In this paper, we do not discuss the communication model thoroughly.

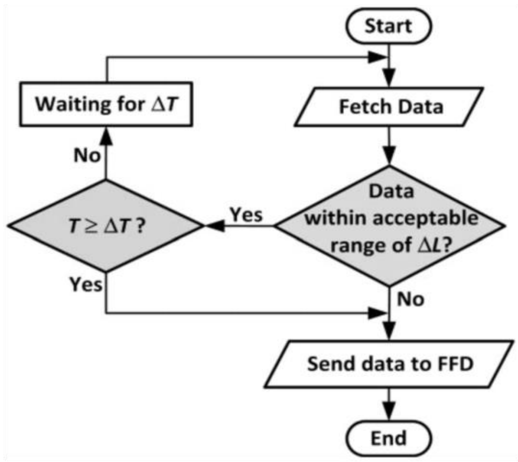


Figure 4. Flowchart of data management [7].

RESULTS AND DISCUSSION

From Figure 1, we assume that the primary voltage is constant, and the transformer's secondary voltage can be increased or decreased such that the voltage all along the feeder is kept within the acceptable limit. We also assume that the system operation assumes that two voltage sensors are installed in the network, one at the beginning of the feeder and one at the end of the feeder.

First, the feeder end voltage is monitored with the help of the installed voltage sensor, and its data is transferred to the master controller. If the voltage at the end of the feeder is above the allowable limit, the master controller provides a proper command to the transformer tap-changing system to activate a lower step. Hence, the voltage all along the feeder will reduce.

After this process, the feeder beginning voltage is monitored with the help of the installed voltage sensor and its data is transferred to the master controller. This voltage should be kept above the minimum allowable limit. Then, if the voltage at the end of the feeder is still above the maximum allowable limit, the process will be repeated to reassure the voltage all along the feeder is within the acceptable limit. Hence, with the help of a transformer with OLTC, the secondary voltage can be reduced up to a minimum of 80%. Figure 5 illustrates the Implementing an automatic tap changer in a three-phase network assuming 5kW single-phase rooftop PVs are installed at all bus along the feeder.

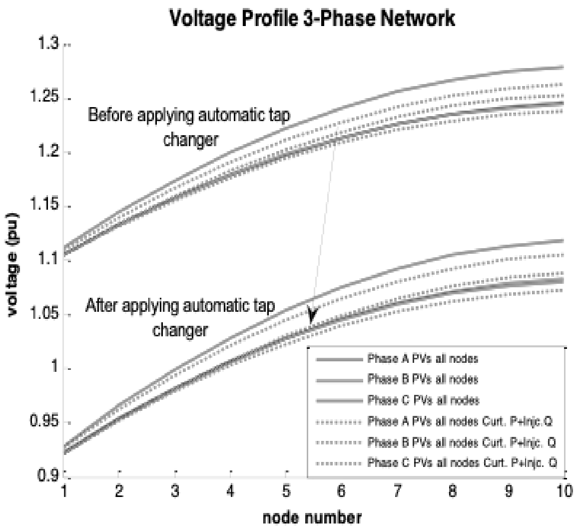


Figure 5. voltage profile with and without OLTC in the network.

To reduce voltage problem due to high PV penetration in the network, the transformer secondary voltage can be slightly reduced with the help of its OLTC feature. In such a case, by applying the OLTC, the voltage profile of the network can be significantly improved.

Anyhow, if we consider adjusting the setting (α) of the OLTC, namely certain low taps, certain middle taps, and certain high taps, respectively, we could see the significant improvement of voltage profile along with the three-phase feeders. Figure 6 illustrates the adjustment of OLTC, α, in flowchart mode, and Figure 7 illustrates the voltage profile improvement.

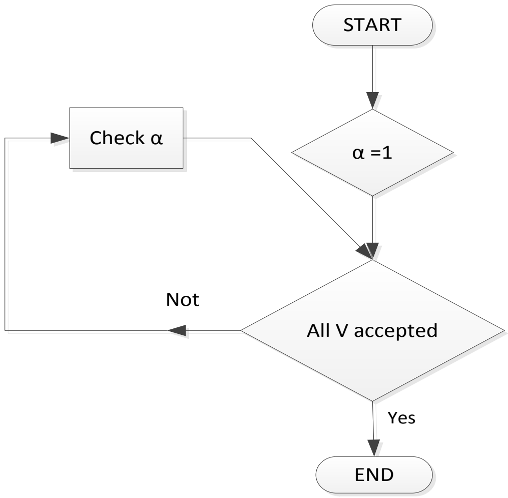
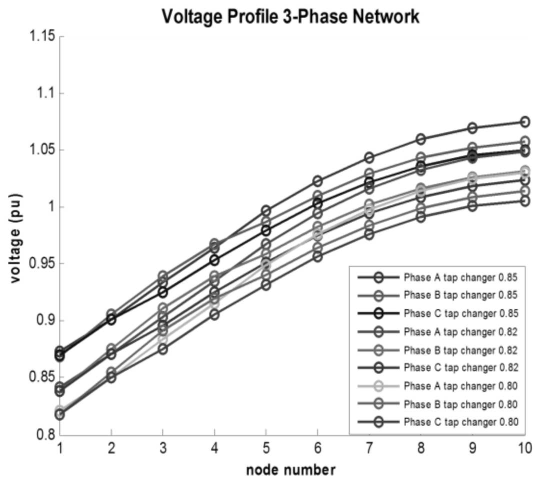
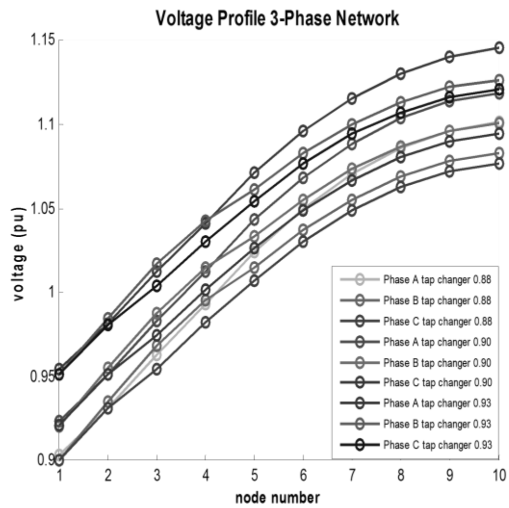


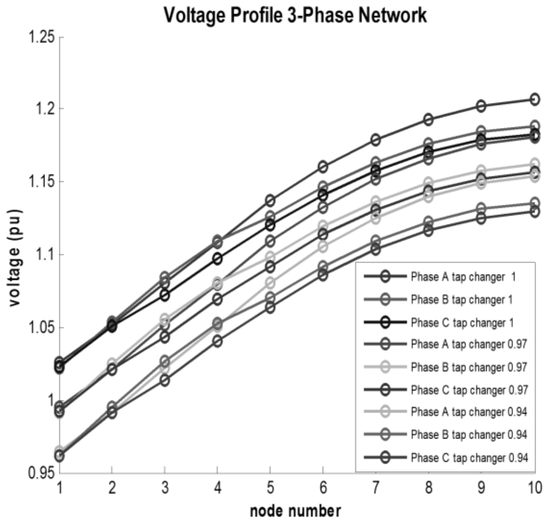
Figure 6. Flowchart of OLTC adjustment, α.



(a)



(b)



(c)

Figure 7. Three-phase voltage profile assuming a massive number of single-phase PVs in the network located at all bus in feeder and tap changer is at varies positions; (a) α is at certain low taps, (b) α is at certain middle taps, (c) α is at certain high taps.

CONCLUSION

The high penetration of single-phase rooftop PV systems that have different ratings and are located randomly within a three-phase residential feeder, can cause voltage rise and unbalance problems for the network. These problems can be effectively reduced if the PV systems are provided with reactive power exchange capability with the network.

Besides, the utilization of a distribution transformer with an on-load tap changing feature can significantly reduce the voltage rise problem in the network.

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