Voltage control using fuzzy logic for radial distribution network with high penetration of photovoltaic generators

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Abstract. Voltage control scheme to enhance the stability for current distribution networks connecting with distributed generation (DG). The increasing demand of energy in recent years transformed traditional distribution grids, which have unidirectional power flow to Active Distribution Networks (ADN), including significant penetration of renewable distributed generators (DGs), such as photovoltaic (PV) modules where the power flow became bidirectional due to the high excess DGs active power that reverses to the power grid. Therefore, this ADN comes with a significant challenge, which is voltage regulation problem. To interconnect PV Generators into distribution systems a robust control approach needs to be adopted, there are different Voltage control scheme can be carried out in variety of methods, such as control by using On Load Tap changers (OLTC), using PV inverters reactive power injection/absorption, real power curtailment process, storage batteries and more. This article proposed a reactive power compensation by PV inverters based on fuzzy logic for voltage control along with the feeders. The control approach was tested and simulated, and it was observed that it can guarantee of maintaining the voltage profile of the distribution network within acceptable range. The MATLAB and Simulink platforms are used to model the system.

1 Introduction

Centralized plants are used in traditional networks to produce the electricity and transferred it till the loads of customers utilizing the transmission and distribution grids whereas, the power flow in these networks is unidirectional. The growing use of clean and natural energy resources such as photovoltaic and wind resources based, the interconnection of large DGs to distribution grid change the direction of the power flow to be bidirectional one [1].
The intermittency of renewable resources, Load location, and network configuration influenced voltage regulation in the distribution network, which may cause overvoltage and Undervoltage in some feeders and also can affect the operation of the existing control equipment [2] for that, the voltage control can be used for better voltage stability and avoid a poor power quality, The voltage control has been used extensively and many publications have been proposed different methods [3]– [4]. Every method is based on one of the following control architectures: centralized control, decentralized autonomous control, and distributed control.
Proposed methods based on centralized control in order to guarantee the voltage profile to be in desirable level. A combination between the DG power factor and varying network parameters has been presented in [5] to minimize voltage stability problem. In [6] DG units output real and reactive power is used to maintain the network voltages within an acceptable range. In [7] A adaptive fuzzy logic-based control has been done of OLTC to regulate the voltage. A decentralized voltage control scheme combined with power factor has been proposed in [8] to optimize voltage level along with the feeders. According to [9] (T.Niknam) "a local control method was introduced to regulate the voltage at buses, where photovoltaic DGs are connected based on a fuzzy logic control for the PV inverters". Coordinated voltage control in [10] is studied to regulate the voltage, the cooperation between real and reactive power of DGs, and the automatic voltage control (AVC) relay for the OLTC of the main transformer at the substation.
DGs reactive power injection/absorption is used in the studies investigation to incorporate and support the operation of OLTC to control the voltage in an unbalanced distribution grid-tied PV system. This paper presents a simulation of a fuzzy controller based on the amount of reactive power injected/absorbed by the PV inverter connected to a specified point of the distribution network. It investigates the effectiveness of the proposed controller with OLTC operation to control the voltage in two feeders of a radial distribution network.
The content of this paper is divided into five sections. Section 2 presents DGs effect in a passive distribution network. A proposed fuzzy control system in section 3. Simulation results using MATLAB/SIMLULINK in section 4 and conclusion presented in section 5.

2 DG effect in passive distribution network

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In a distribution network that contains only loads, the power is delivered to the customers from the main substation transformers, and thus the voltage control is based on unidirectional power flow. However, by incorporating photovoltaic DGs into the network, the validity of one direction of power flow is no longer guaranteed. The DG's real and reactive output power affect the network voltages along with the feeders, this is reflected in overvoltage or undervoltage caused by the unbalance between generation at DG or load variation can be investigated with the two-bus system. Figure1 represents A simplified model of a line section where a DG is connected at the load bus. VS stands for the voltage at the secondary of the distribution transformer at the main substation, VG is the receiving end voltage where the photovoltaic DG is connected. R and X represent the resistance and the reactance respectively of the distribution line, OLTC represents the on-load tap changing transformer. P and Q stand for the real and reactive power flowing across the line respectively, the real and reactive powers of the customer load are P_L and Q_L. P_G and Q_G are the real and reactive powers generated by the Photovoltaic DGs.

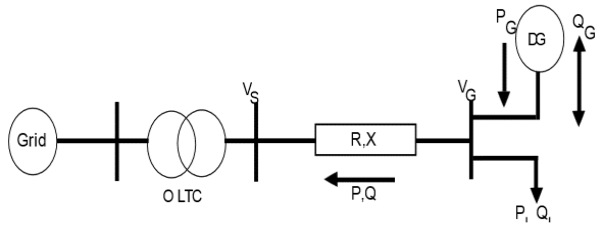

Fig. 1. A simple line section modeling.

Figure 2 shows the Simplified network phasor diagram that representing the voltage drop characteristics.

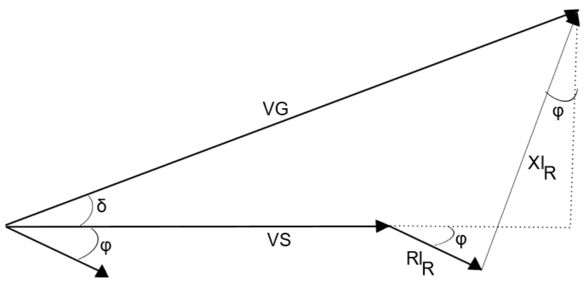

Fig. 2. Voltage phasor diagram in a two-bus power system.

The feeder's resistance is R, and its reactance is X, VS is the voltage at the secondary of the distribution transformer at the substation, VG is the voltage at the connection point of photovoltaic DG, IR is the feeder current, δ the voltage angle between VS and VG, and ϕ phase angle between VS and IR. by using the phasor diagram of voltages photovoltaic DG voltage can be obtained as:

$$\widehat{VG} = \widehat{VS} = \hat{I}(R + jX) \quad (1)$$

The current thought of the feeder is:

$$\hat{I} = \frac{P - jQ}{\widehat{VG}*} \quad (2)$$

$$\widehat{\Delta V} = \frac{RP + XQ}{\widehat{VG}*} + j\frac{XP - RQ}{\widehat{VG}*} \quad (3)$$

The voltage angle is extremely small; hence the voltage drop across the feeder can be approximately equal to the voltage drop's real part. Thus, the equation (3) can be approximated as:

$$|\Delta V| \approx \frac{RP + XQ}{VG} \quad (4)$$

$$|\Delta V| \approx \frac{R(PG - PL) + X(QG - QL)}{VG} \quad (5)$$

By increasing DGs real power injection into the network without any demand on the network, the generation has been restored to the substation, Equation (1) shows VG is greater than VS due to the reverse power flow along the feeder from the DGs towards the substation, therefore, the voltage rises above the upper limit.
To mitigate voltage rise caused by the DGs, there are different solutions, reducing the voltage at the substation, using voltage regulators, installing energy storage systems, allowing curtailment of the DGs, and allowing the absorption of reactive power at DGs. This work is proposed to use the reactive power of photovoltaic DG units to limit the voltage variation along the feeder.

3 Proposed fuzzy control system

In this section an optimal fuzzy-based reactive power scheme is proposed to mitigate the voltage drop or rise in certain feeders due to photovoltaic DG real and reactive power output and also loads variation. The principal reason of using fuzzy logic, it can deal with ambiguous information and map the input with the output even if they were related by nonlinear relations, as well as the decision process of the Fuzzy Logic Controller (FLC) is fast.
The fuzzy controller block scheme is presented in Figure.3. which consider the voltage measurements of the buses connected to DG. These buses are the most which suffer from voltage stability problem. These voltage measurements are collected and compared with reference voltage which is 20KV, then DG units injected or absorbed an amount of reactive power that used to adapt the voltage buses with the reference voltages.

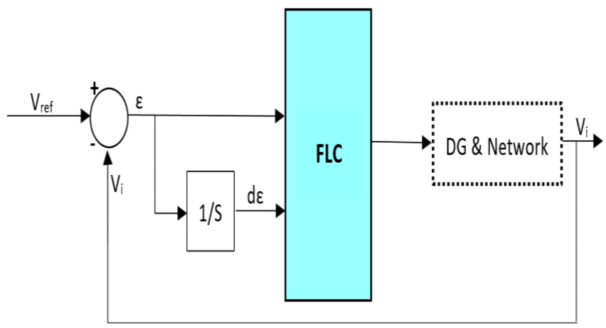

Fig. 3. The proposed fuzzy reference of photovoltaic DG.

The photovoltaic DG unit injects or absorbs reactive power in the network to change the voltage at buses. The fuzzy controller for the photovoltaic DG unit has two inputs, the first can be noted voltage error ε, it presents the difference between the voltage of the bus where it is connected and the reference voltage, whereas the second input is the variation of the voltage error dε, and the output of the fuzzy controller determines the amount of reactive power Qm for increase or decrease the voltage at the DG bus.
The rule base for the DG units can be summarized in Table 1.

Table 1. The fuzzy rules

dε / ε	VN	N	Z	P	VP
VN	I+	I+	I+	I	H
N	I+	I+	I	H	H
Z	H	H	H	H	H
P	A	H	A	A+	A+
VP	H	A	A+	A+	A+

It can be read as follow:

- "IF the ε is NG AND dε is NG THEN the inject the reactive power".
- "IF the ε is P AND dε is P THEN absorb the reactive power".
- "IF the ε is Z AND dε is Z THEN the hold the reactive power".

Where (VN, N, Z, P, VP) are respectively: Very Negative, Negative, Zero, Positive, and Very Positive.
And (I+, I, H, A, A+) are respectively: Inject Plus, Inject, Hold, Absorb, and Absorb Plus.
The membership functions used for ε, dε and Qm are shown in figure.4, figure.5 and figure.6 respectively. Five membership functions that is, "VN", "N", "Z", "P", and "VP" have been used for controller inputs and also five membership functions for the controller output that is, "I+", "I","H", "A", and "A".

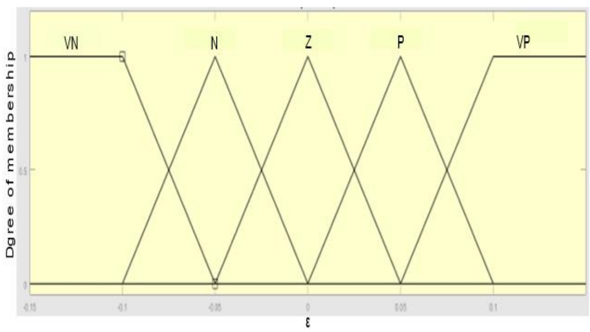

Fig. 4. Input membership function- Error.

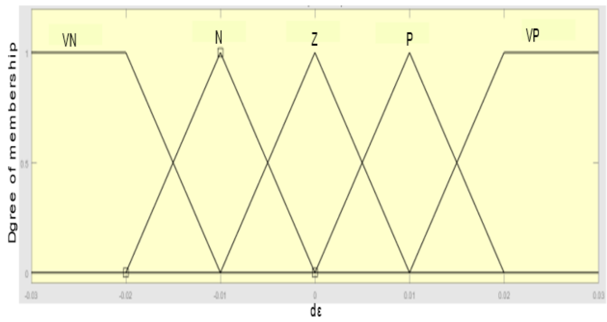

Fig. 5. Input membership function- Error variation.

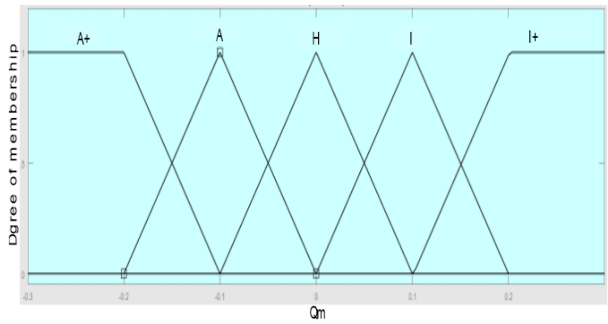

Fig. 6. Output membership function-Reactive power.

4 Results and analysis

This section aims to develop a control strategy based fuzzy logic controller and apply to a 20 kV test distribution network Figure. 7 consisting of two radial feeders, feeder1 and feeder2, the location of 9 MW photovoltaic of DG unit is installed to the substation 5 km away. The network has 10 busbars and 9 variable loads which are supplied by a 40 MVA transformer equipped with an OLTC.

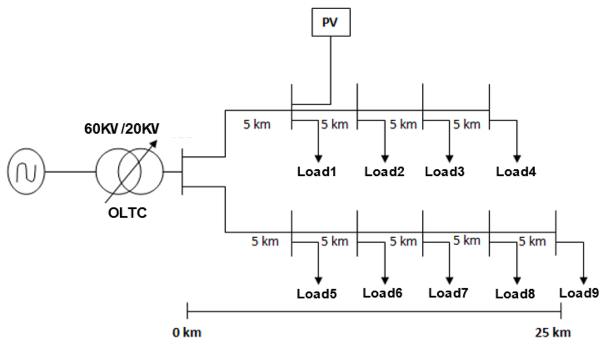

Fig. 7. Two-feeders distribution grid.

The results of the simulation are carried out and examined by using performed and examined by using SIMULINK/MATLAB and 24 hours day was choosing for the simulation purpose. In this network the probability of voltage can exceeds the upper limit at feeder1 is higher due to the flowing of power in the reverse direction, whereas the voltage can exceed the lower limit at feeder2 due to the higher loads and without any connection with photovoltaic DG units. Two examples simulation are were investigated to examine the effectiveness of the proposed controller:

In first simulation. As shown in Fig.8. When the network is only controlled by OLTC, the maximum voltage of the network violates the standard limit 1.05 at 12h whereas the minimum voltage is upper limit 0.95 at 20h.

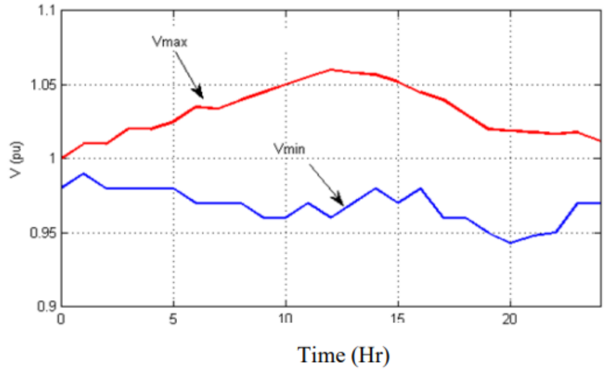

Fig. 8. Voltage level before using fuzzy logic controller.

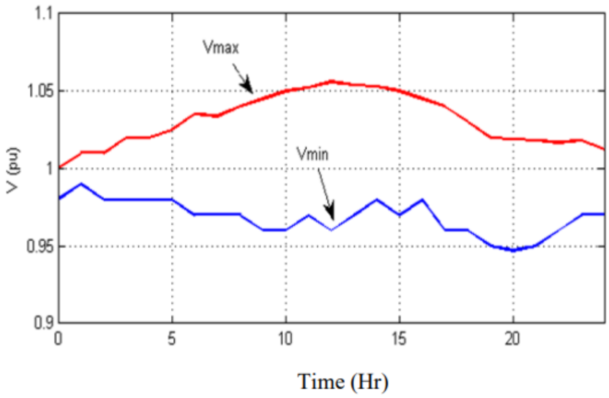

Fig. 9. Voltage level after using fuzzy logic controller.

5 Conclusion

Voltage regulation is one of the primary difficulties that must be addressed in order to assure network stability. A fuzzy logic controller for PV distributed energy resources is presented and investigated in this study. The controller is tested on a two-feeders distribution network interconnected with photovoltaic DG. The controller case study demonstrated the effectiveness of keeping the lower voltages of the network within the acceptable range by injection/absorption PV reactive power, and able to maintain the maximum voltages below upper limit of the network in certain cases. Based on the findings of this study, the controller should be tweaked to reduce voltage rise in various scenarios while also being able to handle a high network size, the controller must be optimized to limit voltage rise in different cases and to be able to handle a large network size. As a continuation of this work, the controller can be adjusted as adaptive fuzzy controller system.

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