Research Article

Fuzzy Multi-Agent Based Distributed Control Scheme for Voltage Regulation in Smart Grids

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Abstract: The integration of large number of DG units among loads may cause severe voltage regulation problem and the utility-side voltage regulators might no longer be able to maintain proper voltage profile. In addition, smart grid provides an optimal set-point design for the voltage/reactive power control scheme of distributed generation through digital control technologies such as monitoring, automatic control, and two way communication facilities to improve the overall performance of the network. The paper proposes new decentralized control approach that has capability to provide proper voltage regulation in smart distribution feeders. Real time simulations are performed to verify effectiveness and robustness of network. Results show that proposed control approach has capability to improve the distribution system voltage profile.

Keywords: Distributed Generation (DG); Multi-agent Systems (MAS); Smart Grid; Decentralized Control

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INTRODUCTION

Voltage stability is integral part of power system stability, in this context it is necessary to maintain the voltage value at an acceptable limits throughout the network. Distribution system has high R/X value and significant voltage drop along the feeders. In a conventional distribution network, a voltage regulator can determine the status of the distribution network by predefined measurements and perform corresponding operations to regulate voltage. However, such a regulation mechanism becomes difficult, when large number of DGs integrate with the network. The proposed project work enables large penetration of renewable DGs while keeping adequate voltage limits thought the network by employing the new digital control strategies [2]. Presently the grid is operated in a centralized manner in which power flow is unidirectional i.e. substation to loads. Centralized control structure with centralized generation has a provision of power at low reliability and poor power quality which cannot guaranteed due to inherent high power losses.

In addition, centralize control mechanism impede several issues like;

- In a small scale generation network, larger number of DG units required to be controlled which might be difficult.
- Increase of uncertainties due to limitation of local measurements, optimization and communication structure.

The devices like line regulators, transformer tap changers (LTC), and shunt capacitors are placed at the substations in order to maintain voltage at standard range along distribution feeders. However, due to lager penetration of DGs voltage regulation by these devices may difficult. The distributed control scheme can overcome issues that encountered in centralized structure, addressing voltage regulation problems in smart distribution feeders. Distributed control mechanism uses local information to independently control voltage at a particular busand also it exhibits implementation of control strategy for individual power devices that contribute voltage regulation. The voltage regulation problem can solved efficiently with a proper coordination among utility devices, resulting in DG units that can provide fast active and reactive power support in distribution network.

The smart grid technologies with distributed control structure can relieve the issues that mentioned earlier.The proposed project work involves multi agent system technology to meet the specified objective. Several number of interacting agents with efficient communication infrastructure constitute Multi agent systems [7]. The main objective of communication system in a multi agent control structure is to enable coordination between components such as LTC, DG and load agents.

The proposed paper is organized as follows: Section II presents related work on voltage regulation in smart feeders. In Section III, the proposed Distributed control structure has been presented. Simulation results obtained in MAT-LAB/SIMULINK has been explained in Section IV. Finally, Section IV summarizes and concludes the work carried out in the paper

II. RELATED WORK

This paper describes an approach for distributed control structure in smart distribution feeders to mitigate voltage regulation problem. The smart grid technologies provide two ways of communication which will facilitate the application of multi-agent control in active distribution networks. The two way communication in proposed control strategy is implemented through expert-based decision making process involving fuzzy membership functions.

Hany E. Farag et al [1], presented A Two Ways Communication-Based Distributed Control for Voltage Regulation in Smart Distribution Feeders. Operation mechanism of proposed control structure in this paper built based on modular intelligent agents. Co-ordination among multi agents can be performed through an expert based decision maker for each controller.

Anna R. Di Fazio, Giuseppe Fusco have discussed “Decentralized Control of Distributed Generation for Voltage Profile Optimization in Smart Feeders” An on-line optimization-based set point design for DG voltage/reactive power control scheme has been implemented to solve voltage regulation problem.

A. Sajadi, H. E. Farag, P. Biczel, and E. F. EI-Saadany et al [3], proposed paper on Voltage Regulation Based on Fuzzy Multi-Agent Control Scheme in Smart Grids in which design and implementation of fuzzy multi-agent based control for voltage regulation has been proposed.

III. PROPOSED DISTRIBUTED CONTROL STRUCTURE

The distributed voltage control scheme uses local information from local measurement units to operate equipment’s on a feeder or substation to independently control voltage at a particular bus. The independent local control units known as agents provide communication among devices.

The proposed distributed control structure composed of several local control units known as agents. These agents have capability to receive or send information between one another. Based on exchanged massages between the agents voltage regulation problem can be solved through fuzzy decision maker. Fig.1 shows block diagram view of proposed distributed control structure, in which LTC agent, DG agent and Load agents are communicated through fuzzy expert based knowledge.

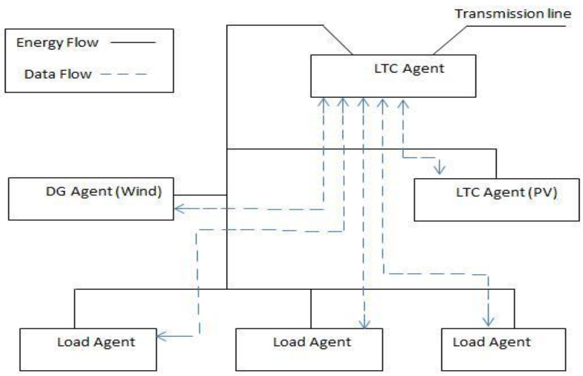

Fig. 1. Block diagram view of proposed system

A. Interior Structure of Agents

The internal architecture of single agent depends on fuzzy controller theory. Fig 2 shows an interior structure of an agent which consists of fuzzifier, interference engine, and defuzzifier. Each agent can receive information from other agent as well as it sends massages to any other agents depending upon the control action. The detected information from the local measurement sensors and from other agents is processed through fuzzifier where crisp values converted into linguistic labels. The inference engine involves in decision making process based on predefined set of values depending on problems encountered. Output is generated in the form of crisp values from defuzzifier[4].

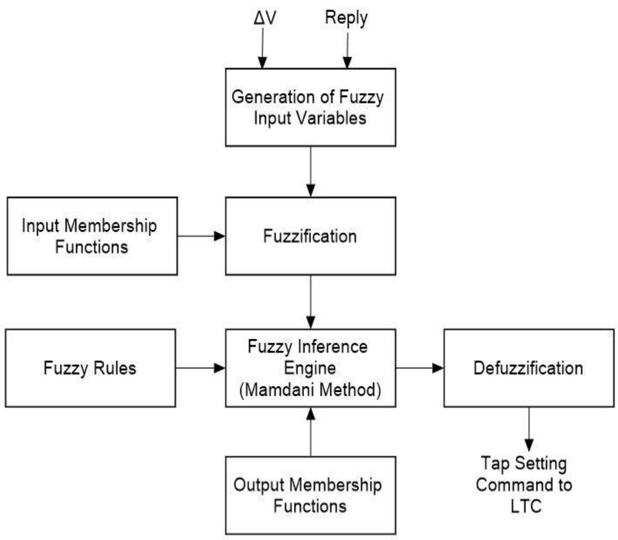

Fig. 2. Internal Structure of Fuzzy Control

In a proposed method the fuzzy inference system computes AND logic with if- and then- clauses. For example "if voltage deviation is positive and permission is accept then Tset is down". Also, "Center of Gravity" method is applied for defuzzification:

$$y = \frac{\sum_{i=1}^{N} \mu(x_i) x_i}{\sum_{i=1}^{N} \mu(x_i)} \text{..........(1)}$$

where, x the value of the "universe of discourse" related to the output variable sampled at N points, and (x_i) is the respective degree of membership, which is formed by taking the union of all the contributions of fuzzy rules.

B. LTC Agent

The main task of the LTC agent is to maintain the feeder voltage at standard range with minimum number of tap operation. Based on previous tap setting data, tap operation takes placeThis agent receives voltage deviation massages from PCC of DG and Load points. LTC agent provides first priority to the massages received by load points rather than information from DG Bus. The LTC agent has two inputs that are Voltage Deviation (ΔV), Permission Massage from DG agent. Similarly this agent has one output i.e. Tset. Fuzzy defined values for inputs and outputs shown in table I.

TABLE I: FUZZY RULES FOR LTC AGENT

ΔV/Perm	**NL**	**NM**	**PL**
UV	UP	UP	NC
Normal	NC	NC	NC
OV	Down	Down	Down

Fuzzy inference system performs the decision making process based on the predefined rules. The command messages will be sent to LTC to decide the tap settings depending upon inputs from load and DG agent. The typical view of membership functions for LTC has been shown in figures below.

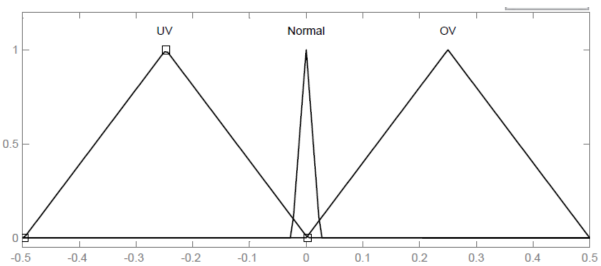

Fig.3 Membership functions for input ΔV

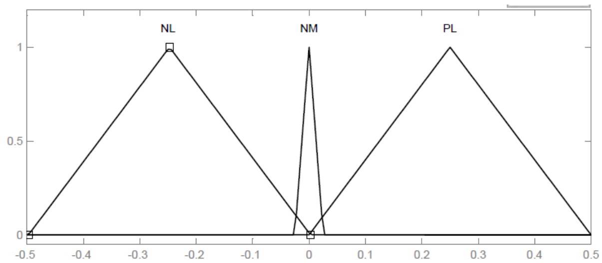

Fig. 4. Membership functions for input Perm

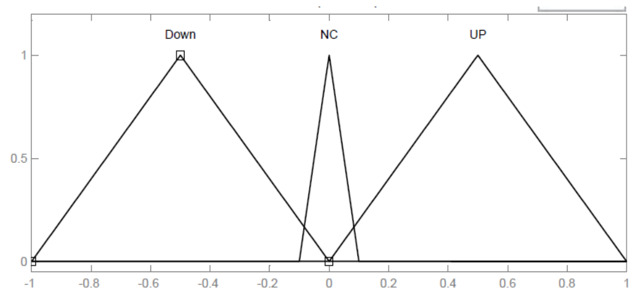

Fig. 5. Membership function for output T_{set}

C. DG Agent

The main goals of DG agent are to keep voltage of its feeder in standard voltage range by keeping generation of DG unit maximum. The voltage deviation at the DG unit connection point is sensed by local measurements. Based on level of voltage deviation, request message will be sent to LTC agent in order to set the required tap. Amount of reactive power available determined from module by using following approach:

$$Q_{g\_av} = \sqrt{S_{nom}^2 - P_g^2} - Q_g^2 \text{.........(2)}$$

Where, "S_{nom} is nominal total power of DG unit, $P_g$is active power generation by DG unit, Q_g is reactive power generation by DG unit, and Q_{g_av} total possible available reactive power by DG unit. The DG agent has two inputs. These inputs are Voltage Deviation (ΔV), and Reply (from LTC). Table II shows their fuzzy defined values.The output from DG agent is Permission (to LTC). The fuzzy rules for DG agent have been shown in table II.

TABLE II: FUZZY RULES FOR DG AGENT

ΔV	UV	Normal	OV
Perm	PL	NM	NL

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An expert based decision making has been performed based on available reactive power and level of voltage deviation at PCC.

D. Load Agent

The voltage deviation at a particular bus is measured by load agent. Control actions are performed depending upon the severity of bus. LTC responds to the load deviation first rather than DG bus deviation. After getting information from the sensor, compares it with maximum and minimum allowed voltage range in the bus, to decide whether over voltage or under voltage has occurred.

$$V_{max} = V_m - V_{max}$$

$$V_{min} = V_{min} - V_m$$

V_{max} and V_{min} values should be positive during normal operation. Vmax will be positive in case of over voltage condition and V_{min} will be positive in case of under voltage condition. These values helps in decision making process.

IV. SIMULATION RESULTS AND DISCUSSION

The proposed methodology is tested on 16-bus distribution feeders shown in Fig. 6 to evaluate the performance of multi agent system communication infrastructure for distributed voltage regulation approach. The test system has been simulated using MATLAB/Simulink. The test system includes two DG units (DFIG and PV) and a LTC transformer with 8 taps connected at substationOne of the DG units is modelled as PV system connected to bus 2. The other one is renewable energy unpredictable source and it is modeled as a 1.5 MW DFIG wind turbine connected to bus 3.

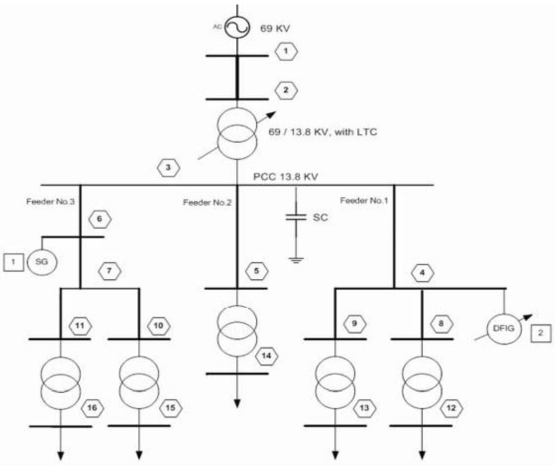

Fig. 6. Case studies system model.

simulink model of 16 bus distribution network with proposed distibuted control structure has been shown in Fig 7.

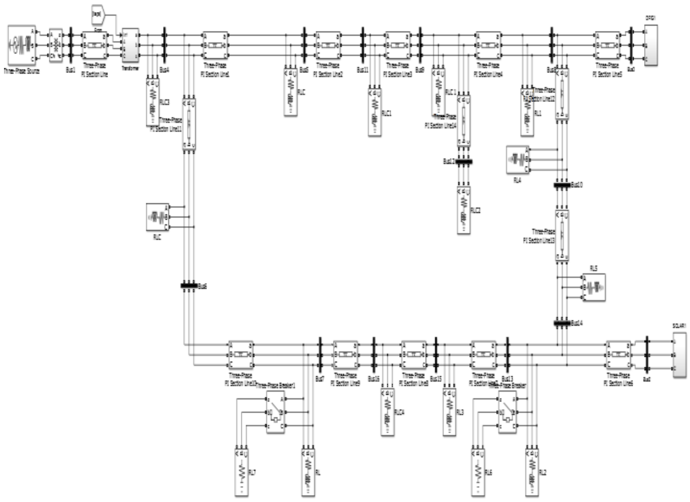

Fig.7. Simulink model of 16 bus distribution feeder

The Load profile on distribution system has been shown in Fig 8.The whole distribution system is referred on 100 MVA base and 230kV base voltage. The power value as seen in figure is mentioned in pu, which is multiplied with base MVA to get actual power ie 18MW to 44 MW.

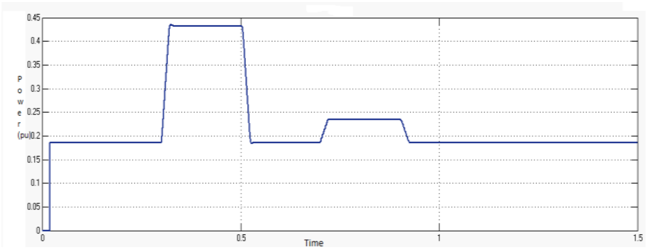

Fig. 8. Load profile on the system

The voltage profile at PCC is shown in Fig 9.and Fig.10. It can be observed that over voltage has been occurred at bus 2 and bus 3 ie voltage is reaching nearly 1.09pu. At 0.3 simulation time, 44 MW of load connected to system and also at 0.7 simulation time another 6 MW connected, as a result under voltage has been occurred, but within 0.2 secs LTC adjusts the tap and voltage profile reaches normal range.

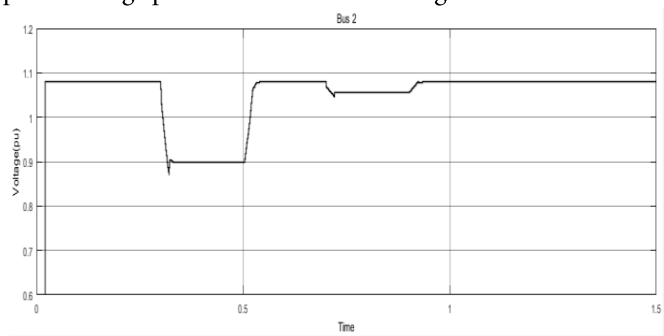

Fig. 9. Voltage profile at bus no 2

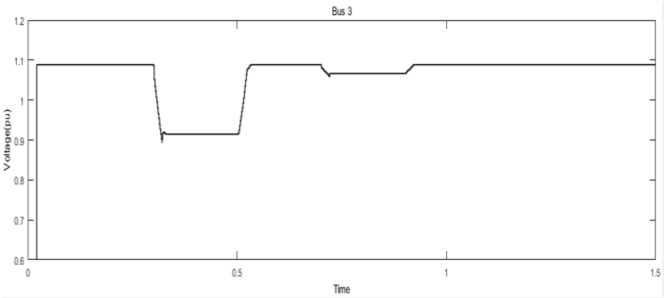

Fig. 10. Voltage profile at bus no 3

Fig.11 shows the voltage profile at different load buses when the LTC performing based on the traditional local control. As it is shown, when the system works with traditional control techniques, three load buses have over-voltage condition. Moreover, voltage profiles at load points are following proportionally load profile.

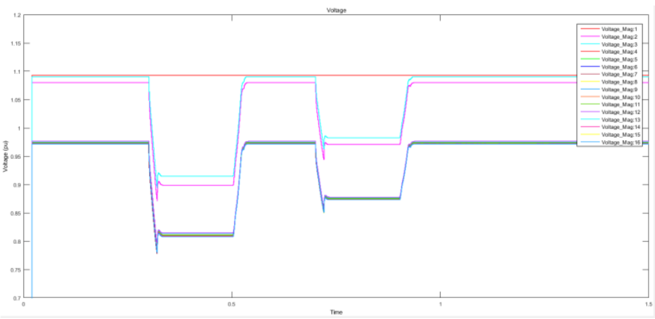

Fig. 11. Voltage profile with traditional LTC Control

The Fig.12 illustrates the capability of proposed fuzzy logic based distributed control scheme of voltage regulation at load point. As it is shown, the voltage at all buses maintained in the range of 0.95 to 1.05 pu. Consequently, LTC operates and regulates the voltages in the feeders. In sum, voltage magnitudes at load buses are kept within standard range properly along with smoother voltage profiles.

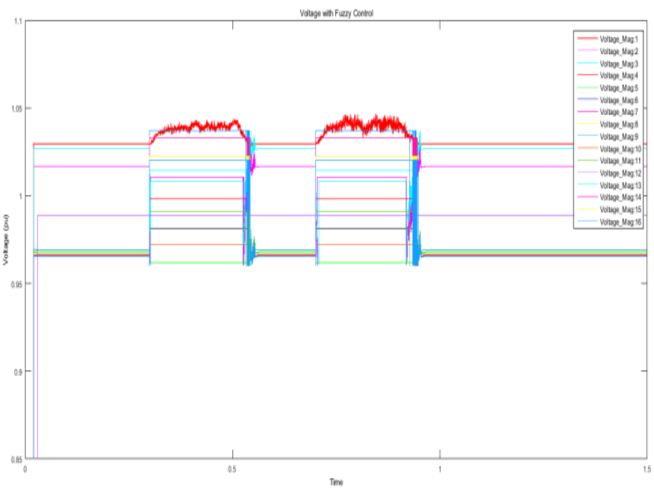

Fig. 12. Voltage profile with fuzzy control scheme

Fig.13 shows the LTC operation involved with fuzzy control technique. LTC performs eight tap operations in order to maintain acceptable voltage range at all the buses.

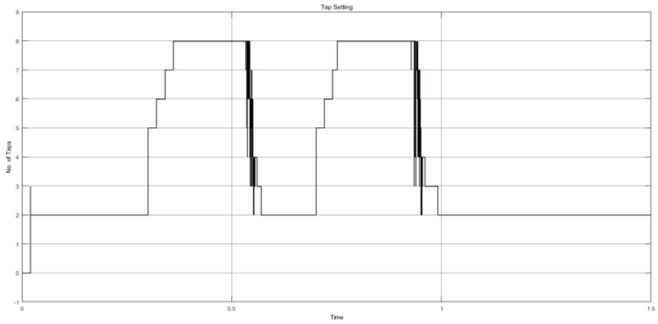

Fig. 13. LTC tap changer operation

V. CONCLUSION

The smart grid technologies such as two ways of communication will facilitate the application of multi-agent control in future active distribution net- works. In this paper a two way communication-based distributed control for voltage regulation in smart distribution grid have been proposed. Theproposed system consists of LTC agent, DG agents, and load agents. In order to investigate capability and applicability of proposed scheme a real time simulation has been performed on standard 16 bus distribution system.

The results are the evidence of capability and superiority of the proposed multi-agent control structure in acceptable regulating the voltage by keeping voltage within standard range. Distributed measurements by placing sensors at load points and communication with LTC were applied. Also the collaboration between agents optimized performance of the tap changer.

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