A Multi-Agent Approach for Decentralized Voltage Regulation in Power Distribution Networks within Distributed Generators

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ABSTRACT

Voltage regulation (VR) is a procedure to keep voltages in a distribution network (DN) within normal limits. Conventionally, a voltage regulator can read voltage levels from predefined measures, and regulate the voltages. However, due to lacking of a distributed generator's (DG) information, the unexpected electricity from a DG will mislead readings on voltages levels, so as to disturb the VR in a DN. Adjusting a DG's reactive power output is an alternative way for VR. However, because of limited penetration levels, DGs need to collaborate with other devices in order to provide an effective voltage regulation. Therefore, how to efficiently manage DGs to coordinate with other electrical components by considering the dynamics of a DN is a big challenge. In this paper, an innovative multi-agent approach is proposed to solve this problem. The proposed approach employs decentralized control of agents on local VR, and also supports agents collaboration on global VR through dynamic task allocation and communication.

Categories and Subject Descriptors

I.2.11 [**Artificial Intelligence**]: Distributed Artificial Intelligence—*Multiagent systems*

General Terms

Power Management

Keywords

Distribution network, voltage regulation, distributed generator, multi-agent system

1. INTRODUCTION

Distributed Generators (DGs), which emerge as alternative power resources in recent years, are considered as one of the most significant technologies in power grid systems [1]. However, a power distribution network (DN) utility usually does not own DGs, and has difficulty in controlling DGs outputs. Therefore, with an increasing level of DGs penetrations, a DN may behave quite differently from conventional operations.

Maintaining consistent and stable voltage levels in a DN is very important for power grids. Voltage regulation is a procedure to keep voltages in a DN within normal limits. On a conventional DN, through collecting sensor readings from predefined measurement points, a voltage regulator can estimate the status of the DN, and perform corresponding operations to regulate voltages [2]. However, such a regulation mechanism may no longer be suitable due to the connection of DGs. To solve such a problem, extra methods must be considered in order to get a fast regulation. Theoretically, voltage levels in a DN are impacted by power delivered through it. If power injected to a DN can be quickly modified, then voltages will be adjusted in a short period accordingly. Conventional bulk generations are impractical due to their large scales, but such a problem does not exist for DGs. Therefore, adjusting DGs power outputs is considered as a matter of course for a fast voltage regulation. However, because of limited penetration levels, DGs need to collaborate with other devices in order to provide an effective voltage regulation. Therefore, how to efficiently manage DGs to coordinate with other electrical components in a voltage regulation by considering the dynamics of a DN, limited information and power resources, and different regulation objectives and constraints is a big challenge in power engineering. Conventional approaches fail to solve such a challenge due to their limitations of flexibility, communication, cooperation, and decision making [3].

In this paper, a novel multi-agent approach is proposed to solve the challenge of voltage regulation. The proposed MAS employs a decentralized organization to dynamically monitor voltage levels of a DN and handles voltage fluctuations by considering the connections of DGs. Multiple objectives and constraints are considered by the proposed agents during distributed voltage regulations, and agents make individual regulation plans through autonomous decision making based on local information and/or collaborations with neighboring agents through communications.

2. DG-BASED VOLTAGE REGULATION

Traditionally, all DGs are required to work in a power factor control model when they are connected to a DN [4]. A linear relationship between a DG's changes on its power

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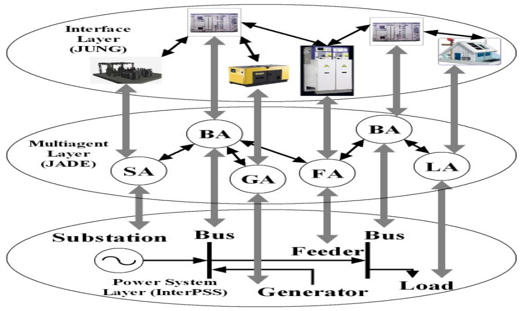

Figure 1: The overview of the system

output and voltage is displayed in Formula (1):

$$\Delta V = \Lambda_{VQ} \cdot \Delta Q + \Lambda_{VP} \cdot \Delta P. \quad (1)$$

where ΔP and ΔQ are a DG's changes on active and reactive power. Usually, in order to minimize impacts to a DN, a DG will only adjust its reactive power output during a voltage regulation.

Three objectives for a voltage regulation are set by considering DGs, which are (i) time objective: $\min \sum_i t(\Delta v_i)$, i.e., the total time spent on the regulation should be minimized; (ii) cost objective: $\min \sum_i \Delta Q_i \cdot c_i$, i.e., the total cost of voltage regulation should be minimized; and (iii) population objective: $\max_i 0.95$ *(p.u.)* $\leq v_i \leq 1.05$ *(p.u.)*, i.e., the voltage regulation should recover problem nodes as much as possible to their normal voltage levels. The fulfillment of the objectives should not lead to violation of operating limits of the components; hence the current limit, voltage limit, and DG's reactive power output limit are also considered during the regulation.

3. A MULTI-AGENT APPROACH

As shown in Figure 1, the proposed approach contains three layers, i.e., a power system layer, a multi-agent layer and a interface layer. The power system layer presents a physical DN. In this paper, we consider five key electrical components in this layer, i.e., substation, feeder, busbar, load and DG. The multi-agent layer presents a multi-agent system to dominate communication, decision making, and cooperation behaviors between the electrical components. Five types of agents are proposed correspondingly, i.e., substation agent, feeder agent, bus agent, load agent and DG agent. The interface layer visualizes the proposed system. Characteristics of the proposed five agents are introduced below.

Substation Agent (SA): A SA represents a secondary substation, and monitors current, voltage and power output of the substation. During a normal operation, the SA continuously exchanges information with neighboring agents, and operates a load tap changer under requests to perform a conventional voltage regulation.

Feeder Agent (FA): A FA represents a physical feeder which delivers power to downstream components, and monitors current, voltage drop, and power delivery on the feeder through communicating with upstream and downstream agents. A FA checks cables transmission abilities to decide whether required power can be delivered. In case a FA is requested to join in a voltage regulation process, it will operate corresponding regulators to fulfill the request.

Bus Agent (BA): A BA represents a physical busbar that conducts electricity between electrical components. A BA records information on connected electrical components, such as current and voltage. Also, neighboring agents limits and capacities are recorded. During a voltage regulation, a BA can make its local decisions on a local regulation plan in order to guarantee its local objectives. Usually, once a BA receives a regulation request from a neighboring agent, the BA will firstly search for a local solution by using only local resources in order to maximize the regulation speed and minimize the regulation cost. If the local resources cannot fulfil the regulation request, the BA will request help from its upstream agents.

Generator Agent (GA): A GA represents a DG. During normal operations, a GA monitors current, voltage and power output of a DG, and maintains the DG's power factor. During a voltage regulation process, a GA provides voltage supports to a DN through adjusting the DG's reactive power output. Also, a GA should ensure that the DG's reactive power output does not exceed its limit. Usually, a DG is ranked by considering its response time, cost and effect on a voltage regulation, and a GA also makes individual decisions on how to respond to neighboring agents regulation requests by considering the DG's capacity.

Load Agent (LA): A LA represents a load in a DN. A LA monitors current and voltage level of the load, and reports to its upstream BA once a voltage fluctuation is detected. Each LA is assigned a priority to indicate the significance of the load. Usually, a LA with a high priority is handled earlier than a LA with low priority during a voltage regulation. Once a regulation plan is determined, a LA will confirm with its upstream agent for execution.

4. CONCLUSION

In this paper, a decentralized multi-agent approach for dynamic and distributed voltage regulations by considering the uncertainty of distributed generators was proposed. The proposed approach not only provides sufficient autonomy for agents to make local voltage regulations, but also supports dynamic agent collaborations for searching a global optimized voltage regulation solution by using agent communication, dynamic task allocation and team forming.

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