Model-free Distributed Control of Microgrids via Broadcast Signals

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I. INTRODUCTION

A smart grid is an electricity network that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both - in order to efficiently deliver sustainable, economic and secure electricity supplies [1]. With the development of distributed electrical resources, more and more distributed generators are connected to the modern power system. However, it is hard to model all the members in control algorithms especially when there are multifarious members in microgrids. A model-free, coordinated distributed control algorithm that can strike a balance between the operators and users will be more suitable for modern distribution network.

Explicit Congestion Notification (ECN) [2] is an instructive algorithm for such a situation, which was first used to determine the choice of routers in a communication network. The basic mechanism was adjusted and used by [3] for the distributed charging of electric vehicles, then the algorithm was extended and renamed as "GECN (Grid Explicit Congestion Notification)" by [4], which used this algorithm to balance the usage of on-load tap changers (OLTC) and elastic loads in primary voltage control. Whereafter, a hardware validation was proposed by [5].

Nevertheless, since the existing algorithm used a conventional Bernoulli model, it is not well suited to control complex processes. To use this algorithm in more complex application scenarios, the algorithm needs to be adjusted and extended again. This paper proposes an improved model-free distributed control algorithm based on ECN, and uses it to balance the active power in the microgrid. In this way, this paper achieves a coordinated, distributed control.

II. METHODOLOGY

A. Basic mechanism

The basic mechanism of the algorithm is based on Bernoulli probability model (0-1 binary probability model). It uses Bernoulli's law of big numbers to provide cohesiveness in system control, instead of exchanging information via powerful communication system. As shown in Fig.1, when the controller (Signal Generator) wants to change something (Temperature, Frequency, Voltage), it will calculate a probability of Bernoulli according to its desire (probability A). In Bernoulli model, there is a binary model whose probability is in [0,1]. If it is extended to minus zone, there will be a -1-0-1 model whose probability is in [-1,1] (absolute value will be used when calculating the results with minus probability, which means if the result is 1, it stands for -1). In this way, probability A denotes the desire of the controller (signal generator) to change something: higher probability means higher desire, positive probability stands for increase, and vice versa. Then the probability will be broadcast to every actuator member in the system (in Fig.1, there are several actuators).

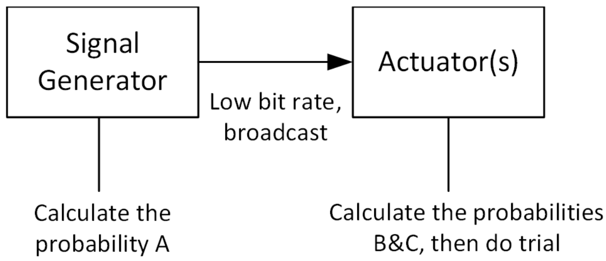

Fig. 1. Basic mechanism of low bit rate broadcast

For actuators, every individual actuator will calculate another Bernoulli probability (probability B) by itself, which is based on its own operating status and denotes the action tendency of this controlled unit (increase, stay or decrease). Therefore, the calculation of probability B can be quite diversified. For example, as to PV, it can be related to sunlight intensity, state of charge (SOC) of affiliated batteries.

After the actuators received the broadcast signal, they will make a decision by doing a Bernoulli trial with the "coordinated probability (probability C)". It is the weighted average of probability A and B, which can be denoted by (1):

$$P_c = \alpha P_A + \beta P_B \tag{1}$$

Where P_C , P_A , P_B are probability C, probability A, probability B respectively, α and β are the weighting factors. The Bernoulli trial will give the final decision. If the result is one, actuator will act, if the result is zero, the signal will be ignored by this actuator. Since the sign of probabilities A and B can denote the action tendency of controller and actuators respectively, their average will work as if they made a compromise, and then figured out the final decision together.

B. Active power balance in microgrid

As introduced in previous section, the proposed algorithm in this paper can deliver a tristate (positive, zero, minus, corresponding to increase, stay, decrease) command from the controller. Assume that the reactive power can be compensated by perfect compensators, then voltage on bus can be used as an indication of active power balance. The controller will look after the voltage on bus and calculate the probability A. The members in microgrids include PV, wind turbines, small diesel generators and various elastic loads. They will act as actuators in such a system.

The voltage difference will be divided in three zones: acceptable, adjusting-needed, and emergency. When the voltage is in acceptable zone, the probability A will be zero, which means no signal will be broadcast. When it is in adjusting-needed zone, there will be a linear relationship between the voltage difference and the probability in (-1,0) or (0,1) (depends on which side it is in), and when it is emergency, the probability A will be 1 (or -1) directly. When probability A is -1 or 1, it will be a mandatory command and actuators have to follow it directly without any calculation (no trial).

For active power control, a broadcast signal is not enough since unlike the switches, the generators or loads need an exact value to finish a typical control process. Therefore, an adjustment coefficient E_{adj} will also be broadcast by the controller, then the adjustment amount for a typical member can be denoted by (2):

$$M_{adj} = S_{in} E_{adj} \tag{2}$$

Where M_{adj} is the adjustment amount, S_{in} is the initial step, which is a constant set by the member itself. Every time after signal is broadcast, the voltage will be measured by controller again, and E_{adj} will be modified by (3):

$$E_{adj}(n+1) = E_{adj}(n) + \lambda[\rho - \mathrm{E}_{adj}(n)], \rho = \frac{E_{adj}(n)}{V'_{differ}} V_{differ} \tag{3}$$

Where λ is a constant in (0,1), V_{differ} is the voltage difference with setpoint before broadcasting, and V'_{differ} is the voltage difference after broadcasting. Parameter E_{adj} is a vector whose elements stands for each operating period in one day. (3) will modify the parameter E_{adj} by exponential moving average (EMA), which can let E_{adj} fits current operating characteristics of the microgrid quickly.

III. SIMULATION RESULTS

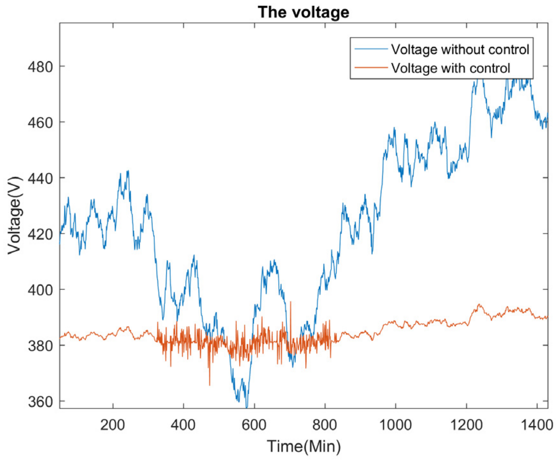

Fig. 2. Active power balance by broadcast algorithm

The algorithm was tested in a microgrid with 14 generators and 16 loads. The profiles and tendency of actuators are generated randomly, to simulate the worst situation. The rated voltage is 380V and constant λ is 0.6. As shown in Fig. 2, after two iterations, the algorithm can reduce the voltage deviation from the range of -6.6% ~ 28% to -3.9% ~ 4.1%.

IV. CONCLUSION

By using a proper probability model, the algorithm can achieve a model-free distributed control with low-byte, single way communication. Additionally, microgrids under such an algorithm are flexible, which means the members can join or quit the microgrid freely, as the self-adjustable parameters with EMA can adapt to the new situations quickly. Since Bernoulli's law of big numbers provides the robustness of the algorithm, the minimum amount of well-proportioned members is a prerequisite, to guarantee the stability of the algorithm.

V. REFERENCES

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