Load Sharing and Microgrid Management Based-Inverter

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Abstract: In this paper presents distributed power sharing control strategy for microgrid management with integration of multiple inverter-based intermittent distributed generators (IDGs) using a need-based aperiodic data transmission scheme. We propose a Multi-agent system (MAS) based discovery algorithm to discover the global microgrid information. According to the proposed control strategy, each bus in a microgrid has an associated bus agent. The control objective is to maintain the supply-demand balance of active power. Further, the distances between neighbor agents have been considered in the threshold of event condition to improve its efficiency in reducing data communication. The proposed distributed power sharing control scheme to a microgrid is simulated using MATLAB/SIMULINK in power system

Key words: Load sharing, Distributed Control, Microgrid, Multi-agent system

INTRODUCTION

Many forms of DGs such as photovoltaic (PV) panels, fuel cells and micro-turbines are interfaced to a power system through electronic inverters [2]– [4]. These interface devices make the energy source more flexible in their operation and control as opposed to the conventional rotational machine-based generators [5], [6]. In recent years, there has been increasing interest in microgrids because these small-scale power systems can offer increased reliability and can facilitate the effective integration of distributed generators (DGs) [1]. A microgrid can be operated either in grid-connected mode or in islanded mode [5]. However, in the islanded mode, the microgrid has to maintain its own supply-demand balance of power which is achieved by load sharing control. In the grid-connected mode, the main grid is able to either inject power into the microgrid for the power shortage or absorb surplus power from the microgrid. Hence, in the grid-connected mode, the main grid is capable of maintaining the supply-demand balance. A common practice in addressing the power sharing control problem is to utilize a centralized solution [7], [8]. In general, these central solutions usually comprise a supervisory control and a machine control. The supervisory control is responsible for providing set-points of DGs, while the machine control is responsible for realizing the set-points. However, these centralized algorithms are usually costly both in communication and computation since they require a complicated communication infrastructure to gather information globally, as well as a powerful central controller to process the large amount of data [9]. Further, such a centralized control scheme is unable to exhibit plug-and-play feature which is required in microgrids [10].

To avoid such negative effects of centralized approaches, distributed control techniques have been proposed for load sharing control of microgrids. For example, a distributed loading sharing approach is presented in [11] based on a signal injection method. However, the complexity of signal injection make this scheme far
from being practical. For this, various distributed droop controllers by emulating the droop characteristic of synchronous generators have been proposed as power sharing controllers [12], [13], which suffer from slow and oscillating dynamic response and steady state deviations. With the development of MAS [14], [15], many consensus based load sharing approaches have been reported and are considered promising methods to provide good performance with the help of global microgrid information discovered by the average consensus of MAS [3], [14], [16], [17]. For instance, a fully distributed consensus-based load sharing protocol is proposed in [16] to ensure active power supply-demand balance of an autonomous microgrid with multiple DFIGs. For microgrids with more general inverter-based DGs, which are capable of modeling various power resources, another consensus-based load sharing protocol is proposed in [3]. Recently, MAS has also been utilized in reactive power sharing control of power grids [18]–[20]. For example, the authors in [18] present a distributed reactive power sharing protocol for microgrids by incorporating MAS consensus theory into the traditional droop techniques. In [21], a distributed averaging proportional integral approach is proposed for active and reactive powersharing by combining droop control with distributed consensus algorithms. Another algorithm by combining these two techniques can be referred to [22]. In order to overcome the shortcoming of droop control, a droop-free mechanism for power sharing has been reported in [23]. For reactive power sharing, the static var compensators (SVC) or static synchronous compensator (STATCOM) are usually required because of the limited capacity of DGs [20].

However, in the aforementioned MAS consensus based load sharing controllers, the information is exchanged in a periodic fashion, i.e., the agent needs to broadcast its state to its neighbors at every iteration. This fashion has been widely used in microgrids due to its ease and simplicity. Unfortunately, it also causes conservative usage of communication network resources while in most microgrids, the processor may have low communicational abilities. Therefore, how to design a distributed load sharing approach for microgrids along with reduced communication feature needs to be further investigated.

II. PROPOSED MICROGRID STRUCTURE

The proposed inverter-based microgrid shown in Fig. 1. In general, the physical layer is an interconnected electrical grid for delivering electricity from suppliers to consumers, and the cyber communication layer is a sparse communication network for supporting the physical layer by providing information of the microgrid.
The microgrid contains multiple distributed generators (DGs) and local loads as shown in Fig. 1. The DGs are represented by electronic inverters which make the energy source more flexible in their operation and control compared to the conventional rotational machine-based generators. Actually, the inverter is an interface between the system and the generator. The generator can be photovoltaic (PV) panels, fuel cells, microturbines, etc [3]. The microgrid is connected to the main grid through a circuit breaker (CB). Hence, it can operate in either grid-connected model or islanded mode. In the islanded mode, the microgrid has to maintain its own supply-demand balance of active power and reactive power in order to guarantee that the microgrid operates autonomously.

\[ P_d = \sum_{i=1}^{n} P_{iL} + P_{Loss} \]  (1)

For most IDGs, namely DGs with intermittent energy source, the available power is limited by environment conditions. For example, the power of PV panels is mainly limited by irradiance levels. Suppose that all inverter-based DGs are driven by intermittent energy source, the supply-demand balance of power can not be maintained if there is a shortage of available power.

Each bus in the microgrid is equipped with a BA aimed to discover the global microgrid information, namely the total active power demand and total available power generation. The proposed load sharing algorithm is fully distributed in the sense that each BA only knows local information and can only communicate with its neighboring agents.

### III. LOAD SHARING

In the islanded mode, the active power setting is determined based on the global power demand and power generation. The total active power demand, \( P_d \), of a microgrid can be formulated as

\[ P_d = \sum_{i=1}^{n} P_{iL} + P_{Loss} \]  (2)

Where \( n \) denotes the number of buses in the microgrid, \( P_{iL} \) denotes the active power demand of load at bus \( i \), and \( P_{Loss} \) denotes the active power loss in the microgrid which is a small percentage of \( P_d \). The total available power generation in the microgrid can be written as

\[ P_{Gmax} = \sum_{i=1}^{m} P_{iGmax} \]  (3)

Where \( P_{iGmax} \) represents the maximum power generation of \( i \)-th IDG, and \( m \) is the number of IDGs. Thence, in order to ensure the balance of supply and demand, the active power generation reference \( P_{iGref} \) of \( i \)-th IDG is designated as

\[ P_{iGref} = U^* P_{iGmax} \]  (4)

With

\[ U^* = \min \left\{ \frac{P_d}{P_{Gmax}}, 1 \right\} \]  (5)

Where \( U^* \) is a common utilization level for all IDGs.

By using merely IDGs, the supply-demand balance can only be guaranteed when the maximum available power generation \( Pmax G \) exceeds or equals to the load demand \( P_d \), i.e., \( P_{iGmax} \geq P_d \). In this case, the utilization
level is set as \( U^* = P_d/P_{G_{\text{max}}} \leq 1 \) for deloading in order to maintain the supply-demand balance. More specifically, the following fact can be easily obtained by combining (3) (4) with (5)

\[
\sum_{i=1}^{m} P_{iG_{\text{ref}}} = \sum_{i=1}^{m} U^* P_{iG_{\text{max}}} = U^* \sum_{i=1}^{m} P_{iG_{\text{max}}} = \frac{P_d}{P_{G_{\text{max}}}} \sum_{i=1}^{m} P_{iG_{\text{max}}} = P_d \quad (6)
\]

Which implies the supply-demand balance. On the other hand, when the maximum available power generation \( P_{G_{\text{max}}} \) is less than the load demand \( P_d \), i.e., \( P_{G_{\text{max}}} < P_d \), the utilization level equals 1. It means that each IDG should operate in maximum peak power tracking (MPPT) mode. In this case, the reliable DG is required to compensate for the power shortage.

Ideally, let \( P_{\text{loss}} = 0 \) whose effects will be compensated by a power loss compensator, and from (5), we have that the calculation of utilization level \( U^* \) depends on the ratio of \( P_d \) to \( P_{G_{\text{max}}} \), which can be written as

\[
\frac{P_d}{P_{G_{\text{max}}}} = \frac{\sum_{i=1}^{n} P_{iL}}{\sum_{i=1}^{n} P_{iG_{\text{max}}}} = \frac{P_{L}}{P_{G_{\text{max}}}} \quad (7)
\]

Where \( P_{L} = \frac{1}{n} \sum_{i=1}^{n} P_{iL} \) is the average of total load demands, and \( P_{G_{\text{max}}} = \frac{1}{n} \sum_{i=1}^{n} P_{iG} \) is the average of total available power. Therefore, the determination of utilization level relies on the average values of total demands and total available power.

### IV. SIMULATION RESULTS AND DISCUSSION

The control block of DG with inverter control is shown in Fig. 2. The inverter control block includes the power regulator (power controller) and the current regulator (current controller) as shown Fig. 2. The inverter control can realize the decoupling control of the active and reactive power by using the Park transform [33].

Voltage source inverter (VSI) and current source inverter (CSI) are the two types of inverter usually used in the inverter-based DG applications. The CSI has been used in grid connection applications due to its simple commutation circuit and feedback diodes free operation [30]. However, with the development of DG technologies, the VSI design has proven to have higher efficiency and faster dynamic response, and thus it is more easily controlled to satisfy requirements of the DG interconnection [31], [32]. In this paper, the VSI is used as the DG interface with the grid.

![Fig. 2. Block diagram of inverter-based DG control](image)

The PI controllers in the power control block aim at providing reference inputs \( i_{d_{\text{ref}}} \) and \( i_{q_{\text{ref}}} \) for the current control block according to the differences of \( P, Q \) and \( P_{\text{ref}}, Q_{\text{ref}} \). The active power output setpoint is provided by the distributed load sharing protocol (DLSP) and a power loss compensator. The power loss is represented by a PI controller driven by the
The maximum bandwidth required by the communication network depends on the number of agents, the frequency at which each agent is sending its messages, and the message size as shown below [34].

\[
\text{Bandwidth} = \text{Number} \times \text{Frequency} \times \text{Message consumed of Agents size}
\]

For the communication network design, there must exist at least one path between any two BAs such that no BA is completely isolated. This requirement is needed in most MAS based applications since we cannot discover information of a completely isolated agent [5], [16]. Meanwhile, like most MAS-based applications, the clock synchronization is required for synchronous iterations to implement the communication network [5], [16]. Moreover, due to the limitation of switching frequency of inverters, the control bandwidth for the inverter is around 1 kHz to 5 kHz [35].

V. VALIDATION STUDIES

In order to demonstrate the feasibility of the proposed distributed load sharing protocol, numerical analysis has also been carried out in MATLAB/SimPowerSystems on the DG model system shown in Fig. 3. This microgrid, whose characteristics are tabulated in Table I, contains four loads, four IDGs, and one RDG. The RDG operates when there is a shortage of power generation. The CB is supposed to be open at \( t = 0.2 \text{ s} \) which means that the microgrid operates in islanded mode from \( t = 0.2 \text{ s} \).

In Fig. 4, the local loads are 1.5, 1.9, 1.5, and 0.5 MW, respectively. Thence, the total load is 5.4 MW with the average value being 1.35 MW. From Fig. 5. Furthermore, the proposed scheme is compared with a time driven load sharing protocol [3], [17], which is implemented as (10) with \( \epsilon = 1/4 \). Fig. 9 shows that the discovered average information can also be obtained with the time-driven load sharing protocol. However, from Fig. 10, we have that our proposed method reduces the communication compared with the traditional one.
Fig. 4. Real power exchange flows
VI. CONCLUSION

In this paper presents distributed power sharing control strategy for a microgrid with integration of multiple inverter-based intermittent distributed generators (IDGs) using a need-based aperiodic data transmission scheme. The control objective is to maintain the supply-demand balance of active power. This is achieved by controlling the utilization levels of IDGs to a common value depending on the total available power and total demands. In order to discover the global microgrid information, we have proposed a discovery algorithm which needs less data communication than most existing MAS based load sharing studies since the agent in our approach only broadcasts its state when an event occurs. The proposed control algorithm has been validated using the MATLAB/ SimPowerSystems simulator on the sample distribution system.

REFERENCES


