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Frequency control using loads and generators capacity in power systems with a high penetration of renewables

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ABSTRACT

High penetration of renewables in power systems would decrease the inertia and frequency control reserve. Hence, preserving the frequency stability of power systems with high penetration of renewables is a challenge. In this paper, a comprehensive frequency control scheme is proposed which uses the capacity of both loads and online generating units coordinately. To preserve the frequency stability while the generating units maneuvering and costumers' inconvenience are minimized, tuning the parameters of the proposed frequency control scheme has been modeled as two multi-objective optimization problems with appropriate objective functions. A proper method has been proposed for solving the optimization problems which is successful in obtaining solutions that guarantee achieving the goals determined for the frequency control scheme. The proposed scheme enables the system operator to optimally manage the frequency control reserve provided by loads and online generating units. Presented results certify that, as decreasing the inertia of the system does not have a considerable impact on the proposed frequency control scheme, it is a good choice to be implemented in power systems with high penetration of renewables.

1. Introduction

In power systems, frequency is a measure of balance between load and generation and should be maintained within the permissible limits for the safe operation of the system. With the ever increasing penetration of renewable energy resources which neither inherently contribute to the inertia of grid nor participate in frequency control (FC), the frequency stability of power systems is endangered [1,2]. On one hand, because of reduction in inertia constant, power systems will experience higher rates of frequency deviation as a result of which generating units will have less time to modify their output power such that the frequency is maintained within the permissible limits [3]. On the other hand, the decreased share of conventional generating units in power generation will reduce their capability of contributing to FC [3]. Consequently, both of the mechanisms which have the key role in limiting the maximum frequency deviation in case of power imbalances are attenuated in power systems with high share of renewables.

In Ref. [4], an H_∞-based control method has been proposed for hydro power plants to improve the frequency response of power systems with a high penetration of renewables. However, integration of intermittent renewables would increase the number and severity of frequency deviations as a result of which wear and tear of the generating units which participate in FC increases [5]. This would increase the cost of participation in FC for conventional generating units. Demand response is an interesting option which would be used for providing fast FC reserve. It has been demonstrated in Ref. [6] that using aggregated demand-side resources to provide spinning reserve, gives grid operators in California a powerful tool to improve reliability, prevent blackouts, and lower grid operating costs. Data transfer is an important factor which affects the cost of providing ancillary services using loads and a lower rate of data transfer would result in a considerably lower cost of demand response [7]. In Ref. [7], 3G internet service has been used as the communication medium for realizing participation of household loads in secondary FC.

In Ref. [8], a new strategy for participation of electric vehicles (EVs) in FC has been suggested. A multi-objective control strategy has been proposed in Ref. [9] for participation of the EVs in FC. A central control scheme, which requires fast communication links, has been proposed in Ref. [10] to incorporate loads in primary frequency control (PFC). Several strategies have been proposed in literature for implementing local controllers for loads to avoid the necessity for fast communication links. However, to improve the performance of the local load controllers, some of their parameters are determined in the control center and transferred to the load controllers via the available communication links. In Ref. [11], three groups of loads are considered for PFC and for each type of loads a specific time-frequency characteristic is considered.

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In order to guarantee the frequency stability of a microgrid (MG) after an unplanned islanding, coordinated control of loads, distributed generators and energy resources has been proposed in Ref. [12]. To implement cooling appliances in PFC, in Ref. [13], their temperature setpoints are altered according to the measured frequency. In Ref. [14], bitumen tanks are suggested for contribution to FC.

In some papers, such as Refs. [11] and [15], ON/OFF parameters are randomized in local controllers to prevent simultaneous connection/disconnection of a large number of loads. Hence, in these methods convenience of costumers would not be effectively considered in the control scheme. Also, as there is no communication between the loads and system operator, systems operator would not have a knowledge of the exact value of the reserve available from loads and cannot consider it for managing the reserve to be provided by the generating units. In Ref. [16], a systematic method has been proposed for determining the optimal parameters of local load controllers and secondary frequency controllers. In fact, tuning these parameters was determined as an optimization problem with several objectives that their weighted sum has been used as the objective function to be optimized using genetic algorithm. Of course determining the proper weight for each objective is not an easy task. Also, by changing the operating point of the system, the proper weights will be different. The objective functions considered in Ref. [16] to be minimized are: the maximum frequency deviation, frequency overshoot and integral of time multiplied by absolute error (ITAE) of frequency. But, wear and tear of generating units has not been considered in the control scheme proposed in Ref. [16] and no objective function is considered for decreasing the inconvenience of the customers which participate in frequency control or the generating units wear and tear.

In this paper, a hierarchical FC scheme has been proposed that uses loads together with online generating units to maintain the frequency stability in case of disturbances. This FC scheme enables the system operator to share the duty of PFC between loads and generating units without the need for fast communication infrastructures. Different parts of this control hierarchy include system operator, generating units, load aggregators and load controllers. Based on the proposed control hierarchy, each part should act such that the main goal of the FC scheme, which is preserving the frequency stability while the generating units wear and customers' inconvenience are reduced, is achieved. To achieve these goals, determining the parameters of generating units and the load aggregators is modeled as two multi-objective optimization problems with appropriate objective functions. A proper method has been implemented for solving the optimization problems. The main contributions of this work can be summarized as follows:

1. A comprehensive FC scheme has been proposed, for the power systems with a high penetration of renewables, which uses the capability of loads and generating units coordinately to reduce wear and tear of generating units and customers' inconvenience as a result of participation in FC.
2. Primary and secondary frequency control (SFC) schemes are coordinated such that loads disconnected within the PFC framework are reconnected in the SFC time-scale with a proper rate that avoids the need for fast activation of SFC reserve provided by the generating units. This would reduce wear of the generating units which participate in SFC.
3. Determining the parameters of the proposed FC scheme is modeled as two multi-objective optimization problems with appropriate objective functions which aim at the goals determined for the FC scheme. The effectiveness of the proposed method in achieving the determined goals has been investigated in different scenarios.

The rest of this paper is organized as follows: the proposed control scheme is presented in Section 2. In Section 3, tuning the parameters of the proposed FC scheme is discussed. An improved frequency response model for the studied power system is introduced in Section 4. In Section 5, using simulation studies, the performance of the FC scheme is examined. Finally, conclusions are presented in Section 6.

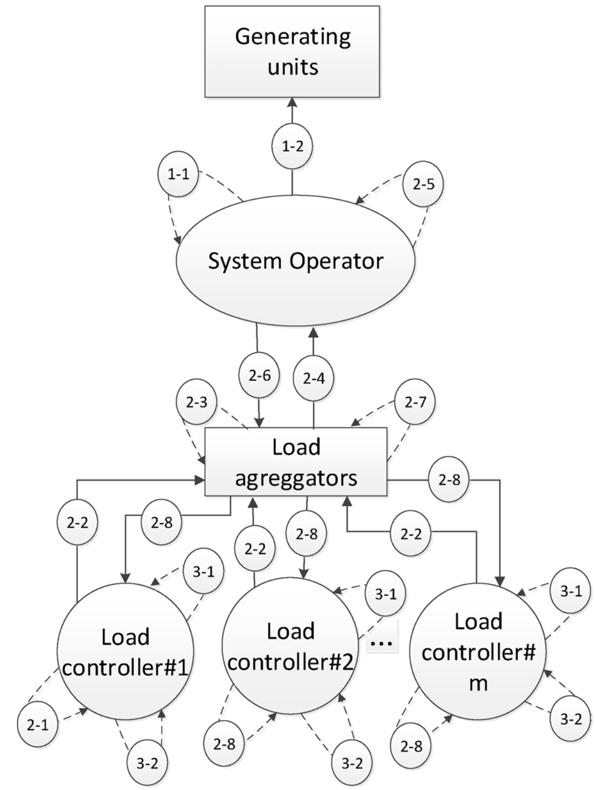

Fig. 1. Schematic diagram of the control hierarchy.

2. Proposed frequency control scheme

Our studies show that although reduction in inertia constant of power systems decreases the PFC reserve provided by generating units before the point of minimum frequency, it does not affect the fast PFC reserve that is naturally provided by frequency dependent loads. It should be noted that however there might be a delay in provision of PFC reserve by some frequency dependent loads such as induction motors [17], this delay is negligible in comparison to the delay in providing PFC by generating units. Hence, it is desired to provide PFC with resources which are able to emulate the behavior of frequency dependent loads. As loads can be disconnected/connected very fast, they are a good choice for providing fast frequency control reserve and their aggregate response would emulate the behavior of frequency dependent loads. In this section, a hierarchical scheme shown in Fig. 1 is proposed to incorporate loads and generating units in FC such that frequency stability is preserved while the generating units wear and customers' inconvenience are reduced. The stages of this FC scheme are presented in the following. The numbered arrows depicted in Fig. 1, show if in a stage data transfer is required or just an internal computation is done. Each arrow also shows the direction of data transfer.

1-1- System operator determines the total value of load damping factor that should be emulated by load aggregators (D_{DR}), speed droop coefficient of generating units and secondary frequency controllers' parameters.

1-2- Speed droop coefficients are sent to the generating units.

For optimal operation of the scheme, stages 1-1 and 1-2 are suggested to be repeated when the load of system considerably changes. Hence, the optimization process required in stage 1-1 would be done offline for several load levels

2-1- Load controllers calculate the parameters which determine the status of loads for participation in FC in the next control interval.