Coordinated control for EV aggregators and power plants in frequency regulation considering time-varying delays

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HIGHLIGHTS

- A coordinated control strategy for EVs and power plants in frequency regulation is presented.
- A robust stability criterion to determine delay margin of frequency control system is proposed.
- The time-varying delays and uncertain inertia are considered in the stability criterion.
- The control strategy can decrease frequency deviations and output variations of power plants.

ARTICLE INFO

Article history:
Received 13 April 2017
Received in revised form 17 May 2017
Accepted 26 May 2017
Available online xxxx

Keywords:
Electric vehicles
Load frequency control
Time-varying delays
Inertia uncertainty
Robust stability criterion
Load demand response

ABSTRACT

Nowadays, large scale intermittent renewable energy is being integrated to power systems as a solution for the low-carbon development worldwide. With the increasing penetration of renewable power generation, system frequency stability is becoming more and more serious. To increase the utilization of renewable energy, electric vehicles (EVs) are suggested to participate in load frequency control (LFC) through aggregators due to their vehicle-to-grid (V2G) capability and quick response characteristic, which is denoted as EV-LFC controller in this paper. In order to fully take the advantages of EVs in the LFC, this paper presents a coordinated control strategy between EV-LFC controller and traditional power plants based LFC (PP-LFC) controller for frequency regulation. In this strategy, the EV-LFC has a priority in response than the PP-LFC when the system deviation violates its acceptable range. However, the LFC integrating EVs is with inevitable time delays due to the data and control signal transmission. Meanwhile, the system inertia uncertainty caused by renewable energy in power system may also cause instability problem. For this reason, an improved robust stability criterion is proposed to estimate the asymptotically stable for LFC system considering the inertia uncertainty and time-varying delays simultaneously. Additionally, a PI controller for EV-LFC controller is used to enhance the system frequency stability. Finally, the effect of increasing EVs number on the frequency stability is investigated, which may guide system operator to utilize EVs to the LFC properly. Case studies are carried out based on a simplified Great Britain (GB) power system. Simulation results show that the proposed coordination strategy can not only provide effective frequency regulation, but also reduce the output of traditional power plants, in which the inertia uncertainty and time delays are properly considered.

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1. Introduction

In order to pursue the low-carbon development around the world, a great deal of large scale intermittent renewable energy is being integrated to power systems. For examples, the wind generation is about 30 GW within a total generation capacity of 100 GW by 2020 in the United Kingdom [1], while the cumulative installed capacity of wind power will be 210 GW by the end of 2020 in China [2]. As a result, the difficulty in frequency regulation is arisen due to the imbalance between the stochastic power output of intermittent renewable energy and load demand, which is a prevailing issue in power system stability research. On the other side, the frequency problem will in turn limit the utilization level of renewable energy in power system and retard the further development of low-carbon power system.
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As rapid development of load demand response [3,4], electric
table (EV) can be used as a suitable source for the load frequency
control (LFC) due to its vehicle-to-grid (V2G) capability. Based on
the existing literatures, the motivations of deploying EVs as a
promising type of demand side resource are listed as follows:

(1) The dispatch of EVs can be achieved through EV dispatch
module, including mobile phone apps, charger, logic com-
puter and database. The EV manufactures, owners, and
power system operators can communicate and respond to
different system operating states [5].

(2) The EVs customer acceptance of the participation in the
demand response can be encouraged by the owners’ behav-
ior and rewards [6,7], which artificially motivate EVs to par-
ticipate in the LFC.

(3) The charging and discharging of EVs are electromagnetic and
chemical processes rather than mechanical processes.
Therefore, the EVs have a much quicker response time than the
traditional power plants to provide frequency response to the
power system [8].

(4) The construction of EVs infrastructure is currently ongoing,
where the charging/discharging modes and EVs’ parking lots
allocation can be optimized together with smart power dis-
tribution networks [9,10].

In view of above motivations, EVs have a great potential to be
one of the most important participants in the demand side
response. The EVs with V2G capability have the ability to provide
spinning reserve [11], and act as an efficient power plant to
decrease the frequent power variation of the traditional generator
[12]. Many control strategies based on V2G were proposed to satis-
fy vehicle user convenience and provide frequency regulation simultaneou
[13-15]. Coordination with heat pumps [16] or bat-
tery energy storage [8] can make the best use of EVs in assisting
system frequency stability. Various LFC controllers based on differ-
ent control theories, such as the fixed structure mixed H2/H1 [17],
output feedback H1 [18] and fuzzy control [19] were designed to
enhance the robust performance against the system uncertainties.
However, the time delays and parameter uncertainties in the LFC
control loops are not fully considered in the LFC.

Time delays exist widely in the LFC control loops [20,21] espe-
sially when some low-cost and heterogeneous communication


data delays in the control process. It is well known that the time delays
usually result in control deterioration and system instability, or
changing the system dynamic characteristics, such as the oscilla-
tion mode and system critical eigenvalues [22]. Consequently,
the determination of delay margin that the system can sustain
without losing its stability, is a key issue in the LFC controller
designing. Some methods have already been proposed to deter-
mine the delay margin [20,23,24] in which the free-weighting
method was widely used [25,26], due to its universality, simple
usage and less conservatism. However, the method has low com-
putational efficiency since a vast number of unknown variables
are introduced which need to be calculated. And an analytical
method with high efficiency in [27].

Another issue discussed in this paper is the uncertainty of sys-
tem inertial, which is affected by the intermittence of renewable
power generation [28,29]. For example, the wind and photovoltaic
generators are usually unable to provide inertia support during fre-
duency event, and the resultant low inertia should be considered
during frequency response process [30]. To cope with these prob-
lems, a robust stability criterion will be introduced into the EV based
controller to treat the time-varying delays. For this reason, a novel method to
determine delay margin, which is used to treat the time-varying delays in the
LFC controller will be proposed in this paper based on the
method with high efficiency in [27].
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