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A new load frequency control approach in an isolated small power systems using coefficient diagram method

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ABSTRACT

This paper applies the Coefficient Diagram Method (CDM) as a new robust controller design of heat pump (HP) and plug-in hybrid electric vehicle (EV) for frequency control in an isolated small power system powered by diesel generator and renewable photovoltaic PV power source. In order to reduce frequency fluctuation resulted from the fluctuating power generation from renewable energy sources, the smart control of power consumption of HP and the power discharging of EV in the customer side can be performed.

The CDM technique has been designed to enhance the performance and robustness against system uncertainties. Simulation studies confirm the superior robustness and frequency control effect of the proposed HP and EV controllers in comparison to other conventional controllers of HPs and EVs like the conventional PID controllers optimized using practical swarm controllers based a specified-structure mixed H_2/H_∞ control design.

1. Introduction

Increasing concern about environmental problems and the shortage and rising costs of fossil fuels have promoted a growing interest in massive integration of renewable energy sources in power systems. Power supplied by renewable sources is intermittent and cannot be easily predicted. These oscillations in the primary power supply can produce instantaneous differences in the necessary balance between generation and demand. As consequences, continuous variations in frequency and voltage levels which negatively affect the electric power system stability usually appear. To tackle these problems there are different Distributed Generation (DG) technologies described as small isolated power systems connected to the grid, are implemented to support and regulate the system voltage and frequency at rural application, large commercial areas and process industries. In most isolated small power system, electrical power is supplied by diesel generators. Additionally, wind generation and photovoltaic generation have gained attention as green energy in most of the small isolated power systems. However, due to intermittent power generations from wind power (WP) and PV, the unbalance between generation and load demand also causes the large frequency fluctuation problem in the small isolated power system. Consequently these problems are also serious in small size isolated grids, and therefore a continuous control on the instantaneous power supplied by the renewable energy sources is required [1,2].

Recently various utilities including buildings and electric vehicles appeared as a result of increasing demand of electric power sources which can increase the chances for rapid fluctuations in loads. However, there are upward trends to install the controllable loads such as HP and EV in isolated grids [3,4]. In [5,6], the HPs and EVs are installed in residential areas for frequency control in the smart microgrid (MG) system.

The practical controller structures such as the proportional integral PI controller, is widely employed in the load frequency control (LFC) application [6]. But this type is considered as a fixed parameters controller which designed at nominal operating points and may no longer be suitable in all operating conditions. For this reason, adaptive gain scheduling approaches have been proposed for LFC synthesis [7–9].

In [10], the practical swarm optimization based-mixed H_2/H_∞ is presented to enhance the performance and robustness against system uncertainties. Despite to the fact that this controller succeeded in its target, but the door is still opened to more techniques to improve the system frequency in face of system renewable power fluctuations and random load disturbances.

On the other hand, a new robust control strategy involving Coefficient Diagram Method (CDM) has been introduced. Basically, CDM is an algebraic approach applied to a polynomial loop in the parameter space, such special diagram called coefficient diagram,

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Nomenclature

ΔP_g	the governor output change
ΔP_d	the diesel power change
Δf	the frequency deviation
ΔP_L	the load change
ΔP_c	supplementary control action
ΔP_{PV}	the photovoltaic power change
ΔP_{EV}	discharging power of plug-in hybrid electric vehicle
ΔP_{HP}	power consumption of heat pump
U_{EV}	control signal of plug-in hybrid electric vehicle
U_{HP}	control signal of heat pump
M	equivalent inertia constant
D	equivalent damping coefficient
R	speed droop characteristic
T_{HP}	time constant of heat pump
T_g	governor time constant
T_d	turbine time constants
$N(s)$	numerator polynomial
$D(s)$	denumerator polynomial
$F(s)$	reference numerator polynomial
$B(s)$	feedback numerator polynomial

Abbreviations

T_{EV}	time constant of plug-in hybrid electric vehicle
CDM	coefficient diagram method
EV	plug-in hybrid electric vehicle
HP	heat pump
PID + H_2/H_∞	PID controller optimized using practical swarm optimization based mixed H_2/H_∞ presented in [10]

which is used as the vehicle to carry the necessary design information, and as the criteria of good design [11].

The CDM is fairly new and not well-known, but its basic principle has been known in industry and in control community for more than 40 years with successful application in servo control, steel mill drive control, gas turbine control, and spacecraft attitude control [12]. In this paper, CDM controller design of HPs and EVs for the load frequency control in an isolated small area power system has been presented. The parameters of the polynomials of CDM technique have been designed based on the dynamic model of the power system.

The power system with the proposed CDM technique has been tested through the effect of uncertainties due to system parameters variation and load disturbance using computer simulation. The simulation results proved that the proposed controller can be applied successfully to the application of power system load frequency control. In order to demonstrate the robustness and performance of the proposed controllers, the proposed CDM controllers of HP and EV are compared with the (PID + H_2/H_∞) presented in [10]. Simulation studies based on the MATLAB program show the superiority robustness and frequency control effect of the proposed HP and EV controllers.

This paper is organized as follows. Section 2 describes the system dynamics and the employed models of the proposed an isolated small power system with the PV–EV–HP as well as proposed CDM controller. Section 3 describes the General consideration about CDM and its Structure. Section 4 presents three configurations for case studies of the proposed an isolated small Power system and analyzes time-domain simulated results of three studied cases of proposed controller with an isolated small Power system under various operated conditions is presented. And finally Specific conclusions are drawn in Section 5.

2. System dynamics

Fig. 1 illustrates an isolated small power system, where PV is used as renewable energy source beside the diesel generator and HPs and EVs are used in this system.

In this section, a simplified frequency response model for an isolated small power system with diesel generator and PV is described [1].

The overall generator–load dynamic relationship between the supply error $(\Delta P_d - \Delta p'_L)$ and the frequency deviation Δf can be expressed as:

$$\Delta f = \left(\frac{1}{M}\right) \cdot \Delta P_d - \left(\frac{1}{M}\right) \cdot \Delta p'_L - \left(\frac{D}{M}\right) \cdot \Delta f \tag{1}$$

where $\Delta p'_L = \Delta P_L + \Delta P_{EV} + \Delta P_{HP} - \Delta P_{PV}$, as shown in Fig. 3.The dynamic of the diesel generator can be expressed as:

$$\Delta P_d = \left(\frac{1}{T_t}\right) \cdot \Delta P_g - \left(\frac{1}{T_t}\right) \cdot \Delta P_d \tag{2}$$

the dynamic of the governor can be expressed as:

$$\Delta P_g = \left(\frac{1}{T_g}\right) \cdot \Delta P_c - \left(\frac{1}{R \cdot T_g}\right) \cdot \Delta f - \left(\frac{1}{T_g}\right) \cdot \Delta P_g \tag{3}$$

where $(\Delta f,\ \Delta P_d,\ \Delta P_g)$ equal to $\left(\frac{df}{dt}, \frac{dP_d}{dt}, \frac{dP_g}{dt}\right)$ respectively, and the block diagrams of the past equations are included in Fig. 3.

The heat pump (HP) and the electric vehicle (EV) are modeled as a first order lag systems [3,4] as shown in Figs. 2, while Appendix A shows a description of the used simplified photo voltaic PV

The block diagrams of the past equations are included in Fig. 3.

3. Coefficient diagram method

In general, the classical control and modern control are mainly used in control design. Additionally, there is a third approach generally called as algebraic design approach [12]. The Coefficient Diagram Method (CDM) is one of the algebraic design approaches, where the coefficient diagram is used instead of Bode diagram, and the sufficient condition for stability by Lipatov constitutes its theoretical basis [10].

The CDM is a technique to arrange the poles of a closed loop transfer function, in order to get wanted response in the time domain [11,13].

In CDM, the design specifications parameters are equivalent time constant (τ), stability indices (γ_i). These parameters have certain relationship with each other which is explained in the design part with the controller polynomials. Coefficient diagram provides to know the stability, time response and robustness characteristics of systems in a single diagram, which is important for systems with large characteristic polynomial degree. Coefficient diagram is accurate and easy to design. The diagram which provides the designer to make a stable decision about the process of the design, cannot be found in other design methods. In coefficient diagram, logarithmic vertical axis shows the coefficients of characteristic polynomial (a_i), stability indices (γ_i) and equivalent time constant (τ) whereas the horizontal axis shows the order *i* values corresponding to each coefficients. The degree of convexity obtained from coefficients of the characteristic polynomial gives a measure of stability, whereas the general inclination of the curve gives the measure of the speed of response. The shape of the a_i curve due to plant parameter variation gives a measure of robustness [11].