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A particle swarm optimization based power dispatch algorithm with roulette wheel re-distribution mechanism for equality constraint

Yu-Shan Cheng [a], Man-Tsai Chuang [a], Yi-Hua Liu [a, *], Shun-Chung Wang [b], Zong-Zhen Yang [c]

[a] Department of Electrical Engineering, National Taiwan University of Science and Technology, No.43, Sec. 4, Keelung Road, Taipei 106, Taiwan
[b] Department of Electrical Engineering, Lunghwa University of Science and Technology, Taoyuan City, Taiwan
[c] Electric Energy Technology Division Power Electronics Department, Green Energy and Environment Research Laboratories, ITRI, Hsinchu, Taiwan

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ABSTRACT

In this paper, a particle swarm optimization (PSO)-based power dispatch algorithm is proposed to deal with the energy management problem of the hybrid generation system (HGS). For conventional PSO method, the search space is only defined by inequality constraints. However, as for power dispatch problems, it is vital to maintain power balance, which can be represented as an equality constraint. To address this issue, a roulette wheel re-distribution mechanism is proposed. With this re-distribution mechanism, unbalanced power can be reallocated to more superior element and the searching diversity can be preserved. In addition, the effect of depth of discharge on the life cycle of the battery bank is also taken into account by developing a penalty mechanism. The proposed method is then applied to a HGS consisting of photovoltaic array, wind turbine, microturbine, battery banks, utility grid and residential load. To validate the effectiveness and correctness of the proposed method, simulation results for a whole day will also be provided. Comparing with three other power dispatching methods, the proposed method can achieve the lowest accumulated cost.

1. Introduction

Recently, renewable energy has attracted worldwide attention due to exhaustion of fossil fuel as well as concerns over greenhouse gas emission and security requirement of energy. Especially after the Fukushima nuclear power plant disaster, human beings start to reflect on the way of producing energy and try to figure out the possible alternative resources. In fact, renewable energies including solar power and wind power feature the characteristics of environmental sustainability and less emission, so they have been regarded as a green power source compared with fossil fuel. Governments all over the world have put researching emphasis on making good use of these natural sources and also developed policies to promote their applications in the last decades. With the progress made on the technical performance, the cost of technologies for renewable energy descends remarkably and the breadth of applications broadens rapidly. Now in the energy market, renewable energy becomes a popular power generation candidate. However, most of the renewable energies are intermittent and highly dependent on weather conditions. Hence, it is crucial to incorporate the power storage equipment with renewable energy system to compensate insufficient power or absorb surplus. Also, power converters are essentially employed to keep the output voltage from varying with different loads. But the variation in both load demand and power sources together with the output power limits of power converters still make practical implementation more complicated. As a result, the integration and operation of a hybrid generation system (HGS) involve a variety of variables to be concerned [1–5].

According to previous studies, the schemes of HGS can be categorized into standalone and grid-connected types. No matter in which kinds of framework, there are numerous approaches developed to address issues and realize energy management. For instances, in standalone scheme Ref. [6–9] proposed supervisory strategy to satisfy load requirements while considering the constraints of storage systems. Through mathematical method, Marzband et al. [10] developed a power dispatch strategy based on mixed-integer nonlinear programming (MINLP) to obtain cheapest

* Corresponding author.
E-mail address: yhliu@mail.ntust.edu.tw (Y.-H. Liu).

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price and maximum utilization of distributed energy resources. In Ref. [11], the constraints were formulated into mixed-integer linear programming (MILP) models and power curtailment strategies were integrated in the load and power management. In addition, Metaheuristic methods are widely applied in the field of HGS. Based on economic analysis, Kalantar et al. optimized the proposed stand-alone hybrid system consisting of wind turbine, microturbine, solar arrays and battery storage by genetic algorithm (GA) [12]. To extract the maximum energy from renewable resources, a supervisory control strategy is applied and demonstrated for one day. Similarly techniques can also be found in Ref. [13]. Feroldi et al. combined a bioethanol reformer to the hybrid generation system to produce sufficient hydrogen to feed fuel cell systems. The models integrated into the hybrid power system were established and their sizes were optimized by GA. Based on state machine approach, the energy management technique can properly coordinate different energy sources [14]. García et al. modeled the components in hybrid system mathematically and proposed an hourly energy management combining fuzzy logic controller (FLC) based supervisory system and cost optimization controller. Simulation of the system for 25-year duration was considered [15]. Berrazouane et al. employed cuckoo search (CS) to optimize the FLC which determined the operations of battery bank, photovoltaic (PV) systems and diesel generator and hence the minimizations of multiple goals including loss of power supply probability, excess energy and levelized energy cost can be realized [16]. Lujano-Rojas et al. predicted wind speeds and load power to minimize the energy supplied by the diesel generator and battery bank [17]. Regarding standalone microgrids and systems of microgrids, Giaouris et al. employed decision making models to develop complex power/hydrogen management strategies [18]. Torreglosa et al. developed a hierarchical control strategy which is composed of a master control and a slave control. Master control strategy is responsible of determining reference powers while the slave control strategy modifies those references to satisfy the dynamic limitations. The proposed method is carried out on the standalone hybrid system for a long-term 25 years simulation [19]. Moreover, multi-objective optimization problems in HGS are also investigated by various studies. For instance, Sharafi et al. proposed a particle swarm optimization (PSO)-based method to tackle a multi-objective optimization problem that aims to minimize the total operation cost, fuel emissions and loss of load probability [20]. In another similar study, Abedi et al. used differential evolution (DE) algorithm accompanied with fuzzy technique [21]. As for grid-connected scheme, Khanh et al. took solar power levels into account and determined control modes of fuel cell (FC). Through the minimization of the number of mode changes, PV and FC can be operated at the maximum power point and at high efficiency, respectively [22]. Marano et al. integrated a compressed air energy storage system into the hybrid power generation system and presented a thermo-economic analysis. The dynamic programming algorithm is also implemented to minimize operational costs for one day [23]. Baziar et al. designed a θ-PSO algorithm with three sub-modifications where appropriate modifications are selected by roulette wheel (RW) mechanism. Also, the uncertainties including load demand forecasting error, grid bid changes and wind turbine (WT) as well as PV output power variations were considered based on 2 m point estimate method concurrently [24]. The proposed method was compared with other PSO based approaches on a typical grid-connected micro-grid (MG) for 24 h. Boukettaya et al. designed a supervisory strategy for a micro-grid power system consisted of wind and PV generation subsystems, a flywheel storage system, and domestic loads connected to grid. The proposed strategy is able to switch the operation modes in order to minimize the operational costs [25].

From the description stated above, metaheuristic methods can be utilized to tackle the energy management problems of HGS. Among them, PSO provides a simple and effective approach that can be applied to optimization problems. Therefore, it is chosen in this study to deal with the power dispatch problem. However, available power of different generator components is restricted. Thus, the boundaries of searching space for particles are defined. In addition, one of the most important issues for power dispatch is the power balance between power suppliers and absorbers, which is generally expressed as an equality constraint. Whereas, particles in PSO are governed by the combination of random factors and experiences from self and swarm. Therefore, the equality constraint might destroy the intrinsic of searching behaviors. To apply PSO method on power dispatch problem, there is a niche to deal with since the exploration of particles might be limited and lose the diversity [26–28]. In this paper, a PSO-based power dispatch algorithm with roulette wheel re-distribution mechanism for equality constraint is developed. With the roulette-wheel based re-distribution mechanism, the particle can search in sparser area rather than be limited to some specific dimension when dealing with power balance issues. In this paper, the design procedure of the proposed PSO-based algorithm will be described in detail. In addition, a penalty mechanism which takes the battery state of charge (SOC) operating range into account will also be presented. The proposed method is then applied to a HGS consisting of PV array, WT, MT, battery banks, utility grid and residential load. Simulation results for 24 h will be provided to validate the effectiveness and correctness of the proposed method. The rest of the paper will be divided into the following sections: In Section 2, the system description is given and the mathematical models of the

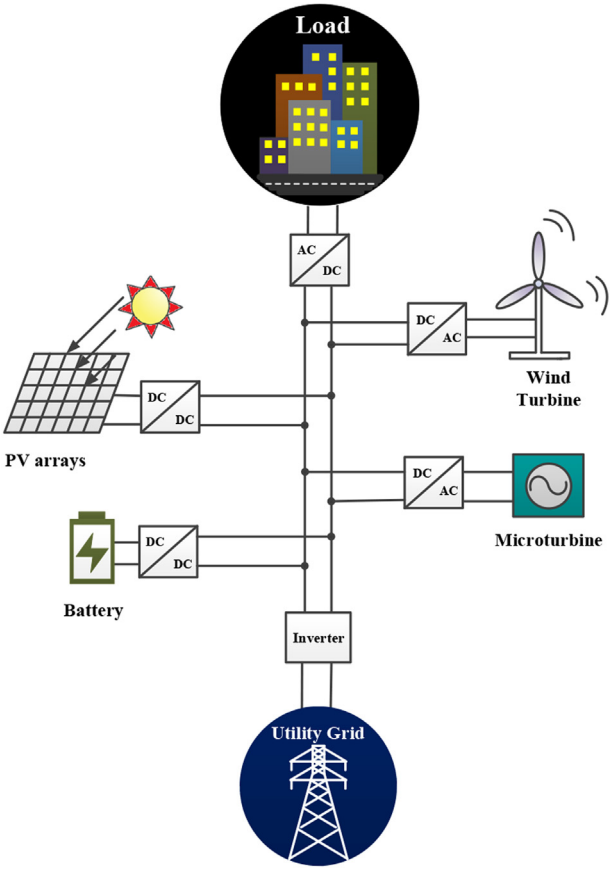

Fig. 1. System diagram.