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ADALINE (ADAptive Linear NEuron)-based coordinated control for wind power fluctuations smoothing with reduced BESS (battery energy storage system) capacity

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ABSTRACT

Most wind turbine generators installed in large wind farms are variable speed types which operate at the maximum power point tracking mode in order to increase the power generation. Due to this fact and regarding the random nature of the wind speed, the output power of the wind farm fluctuates randomly. Fluctuating power affects network operation and needs to be smoothed. In order to mitigate the output power fluctuations of a wind farm, a 4-step coordinated control technique based on ADALINE (ADAptive Linear NEuron) is proposed in this paper which uses a small BESS (Battery Energy Storage System) capacity. At first the on-line tracking of the WFOP (Wind Farm Output Power) is carried out by ADALINE. Afterwards, two constraints for maximum permissible fluctuations are imposed on the ADALINE output. Two states of charging feedback control strategies are implemented in the third and fourth steps. Reducing the battery capacity in proposed coordinated control technique is fulfilled through the accurate tracking performed by ADALINE and also by maintaining the level of BESS saved energy within the batteries safe performance region performed by state of charging feedback control strategies. Simulation results run by real data verify that the performance of the proposed approach is considerably better than the basic approach.

1. Introduction

Global warming along with persuasion of environmental organizations to decrease greenhouse gases on the one hand, and increasing demand for electrical energy and its growing final price on the other hand have attracted the attention of governments and different societies to renewable energy resources [1]. Wind is one of the renewable energy resources possessing characteristics distinguishing it from others. However, emergence of the wind energy in electrical networks and increasing the power production in wind farms resulted in some new challenges too. Because of their high final cost compared with other parts of the power generation network, wind turbines need to work at the maximum power point tracking mode [2]. Due to this fact and regarding the random nature of wind speed, the output power of the wind farm fluctuates. The effect of fluctuations on the system stability is more significant when the wind farm capacity or the wind power production part in the whole power system increases. This is a challenge which may lead to the power system collapse in unsuitable situations [3]. So far, various researches have been conducted in order to mitigate fluctuations of WFOP (Wind Farm Output Power).

A large majority of studies demonstrated that wind power fluctuations can be mitigated by blade pitch control [4]. However, mechanical stress may damage blades if the pitch angel control operates fast enough to mitigate short-term fluctuations. Utilizing ESSs (Energy Storage Systems) by different technologies has been recognized as another acceptable solution to smooth wind power fluctuations [5–7]. In Refs. [8] and [9] some approaches based on pumped storage and compressed air energy saving have been studied which have a low dynamic adjustment speed and it is not suitable for large wind farms. Implementing SMES (Superconducting Magnetic Energy

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Storage) has been recommended in Ref. [10], but it is not cost-effective. The solution proposed in Ref. [11] is use of SCES (Super Capacitor Energy Storages) which together with the BESS (Battery Energy Storage System) technology form the HESS (Hybrid Energy Storage System) technology. Also, Lithium-ion battery is an energy saving technology with a high energy density and acceptable energy efficiency which has notable potential in power fluctuation smoothing applications [12,13]. In most wind farms, BESS is utilized alone or together with SCES.

In addition to ESS, the smoothing process needs a control system for COD (Charging Or Discharging). Control methods are usually based on First-order FLF (Low-pass Filter) which is suitable for real-time applications and is implemented easily [14]. The WFOP becomes smoother after tracking by FLF control. Most of previous researches have focused on the basic FLF method with fixed time constant [14]. In Ref. [15] a rate limiter has been added to FLF in order to limit the maximum output power fluctuations. Also, a knowledge-based ANN (Artificial Neural Network) control system has been integrated with FLF for scheduling wind power supply in two time-scales using two storage systems in Ref. [16]. Although fluctuations decrease by using a large fixed time constant, it increases the needed saving capacity. Conversely, small time constant increases the output power fluctuations despite of lessening the needed saving capacity. Due to this fact, flexible time constant for FLF has been suggested in Refs. [17–19]. Another solution is to use wavelet transform instead of FLF, a frequency distribution allocates wind power fluctuations to the different HESS components to more easily satisfy 1-min and 30-min fluctuation mitigation requirements [20]. High frequency low density energy is saved in SCES and low frequency high density energy is saved in BESS [19,20]. This approach is usable just in the wind farms equipped with both the BESS and SCES technologies.

In order to decrease the needed BESS capacity, some coordinated control methods has concentrated on optimum utilization of BESS safe performance region. For example, in Refs. [21] and [22] a SOC (State Of Charge) feedback control method has been added to the basic FLF for keeping the battery SOC within the correct range. In Ref. [23], a chain rule control mode with the factors of SOC, cycle limit current and battery life is used to realize the optimal control of a power smoothing system.

In order to mitigate the output power fluctuations of a wind farm, a 4-step coordinated control technique is proposed in this paper which uses a low BESS capacity. ADALINE is employed in the tracking step of output active power. Precise and fast tracking, high operation speed and simple practical implementation are excellent specifications of ADALINE. In the second step, two constraints defined by utilities are applied to the ADALINE output (more details have been addressed in Section 4.1). In the third and fourth steps, two control strategies make the best possible use of the battery safe performance region by controlling the level of remained energy in the BESS.

The remainder of the paper is organized as follows: Section 2 provides some background on basics of the wind PFS (Power Fluctuation Smoothing) and introduces the FLF-based control approach. In Section 3 constraints of the wind farm power fluctuation mitigation imposed by utilities is described. The proposed control approach for PFS is elaborated in Section 4. Simulation results, comparison, and discussion are presented in Section 5. Conclusion and references develop Section 6 and section 7 of the paper respectively.

2. Basics of wind farm PFS

Fig. 1 shows the configuration of a wind farm connected to the ESS and the power network while P_{WF}, P_{co} and P_E indicate WFOP, COP (Combined Output Power) injected to the network and power exchanged by the ESS respectively.

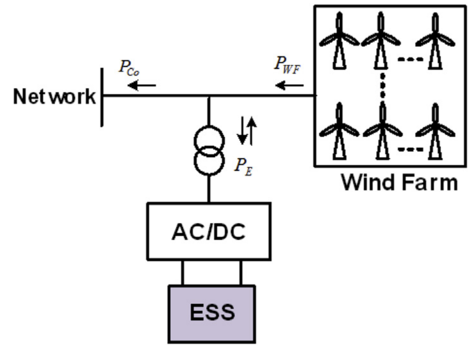

Fig. 1. Configuration of a wind farm connected to the ESS and the power network.

In fact, the WFOP cannot be injected to the network directly because of the unpredictable fluctuations. Inevitably, the fluctuations need to be smoothed before injecting to the network. In the process of the smoothing, use of the following items is necessary:

1) ESS
2) A control system for energy charging/discharging

Depending on the wind farm capacity, the BESS or the HESS may be employed.

The most inexpensive and the easiest approach is to use a FLF as shown in the power fluctuation smoothing control system of Fig. 2.

In this method, the WFOP is fed to a FLF with a given time constant T_F. Then $P_{WF}(s)$ is compared to $P_o(s)$. If $P_o(s)–P_{WF}(s) < 0$, then $P_E(s)$ is saved into the ESS; if $P_o(s)–P_{WF}(s) > 0$, $P_E(s)$ should be provided by the ESS.

3. PFMC (power fluctuation mitigation constraints)

It is ideally expected that the COP has always a constant value. In this case a very high capacity ESS is required which is extremely costly and practically unfeasible. So some constraints determined by utilities are applied to the smoothing process. These constraints vary from country to country in different manuscripts. For instance, in a research conducted in the United States [24], the power ramp constraint has been considered the average power of 1 min so that the instantaneous ramp up and ramp down should be at most equal to 5 percent of the average power in 1 min. The maximum power ramp rate is 10 percent of the rated power per minute for wind power systems in Germany and in Ireland, there are two specified ramp rate settings of 1 min and 10 min [25]. Utilities in Japan introduced two 1-min and 20-min power ramp rates that allows the COP of the wind farm to have fluctuations up to 2 percent and 10 percent of the wind farm rated power per each 1-min time window and 20-min time window respectively. Also, different constraints have been implemented in China. For instance researchers in Ref. [26] declare that two 1-min and 30-min constraints are necessary for the ramp rate of the wind farm COP. These

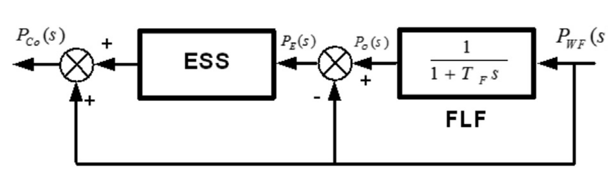

Fig. 2. Power fluctuation smoothing based on the FLF method.