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Semi-dispatchable generation with wind-photovoltaic-fuel cell hybrid system to mitigate frequency disturbance

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ABSTRACT

Variability of large-scale wind and solar energies as power sources creates a disadvantage and a challenge for frequency control in distribution networks. In this work, an Advanced Energy Management System (AEMS) for a hybrid generation system is proposed. The AEMS is based on tracking the load curve or final user's required power to be supplied by a model predictive control design. The aim of the presented method is to propose an energy management system for massive integration of hybrid systems as distributed generation without influencing the network frequency. The main advantage of the proposed approach is to overcome the influence of frequency instability, using forecast and predictive control. The designed method uses probabilistic information for short-term wind and photovoltaic power generation as an input of the management system; hence the outcome of the hybrid system is the power demanded by the store. A case study displaying the performance of the AEMS developed is presented. Historical data of wind speeds, solar radiation and load profiles are used to control the output power generated by a hybrid system. The proposed energy management approach provides the liberty to manipulate the output power of the hybrid system considering the system boundaries without disturbing the network frequency.

1. Introduction

Frequency stability is a problem when implementing renewable energies as power generation if connected to the network. In the electric network frame, there are three levels of frequency control, each of them working at different time scales. Distributed generation (DG) at distribution level with renewable energies directly has an impact on the tertiary frequency control as consequence of the unpredictability in availability; thus, large-scale DG can influence even the primary frequency control as the effect of fewer reserves caused by less conventional generation available [1].

Forecasting has become more widely used as a tool to facilitate the fluctuating generation integration into electric power systems. Many studies are focused on modelling wind power forecast where different models are explained [2,3] and compared [4], and solar radiation forecast approaches are developed [5,6]. Energy storage system (ESS) has been proposed for reducing the variability. In [7], the design of a supercapacitor required as ESS for a wind farm by means of a statistical approach is proposed, implementing optimistic random wind power input. Several approaches use ESS for concentrated solar power (CSP) in order to shift the generation to hours with high energy prices as in [8], focusing on the production for participating in the day-ahead market [9], and on the conditions for optimizing the microgrid operation for achieving economic efficiency in the operation management [10]. A wind power system with battery storage is analysed in [11], where the charging time of the batteries implemented and a method for determining the expected charging time are proposed.

Recently, a wide variety of studies have been performed on the optimal energy management in renewable energy systems. The literature on optimal semi-dispatchable management applied to hybrid systems as DG is still lacking. However, several works analyse the integration of energy systems with storage, giving priority to competition and estimation of the electricity market as [12], even from the point of view of home energy management systems [13,14]; another study, optimize the utility grid and the area of an installed PV system in order to have a cost-effective energy system as in [15]. Likewise, the use of smart energy management algorithm in hybrid energy storage systems, based on systems with battery and ultra-capacitors, to solve the intermittence of renewable is contemplated [16]. Furthermore, optimization strategies carried out on a hybrid system still consider the need for fossil power plants [13,17,18].

The innovation of this paper, compared with other methods, is the

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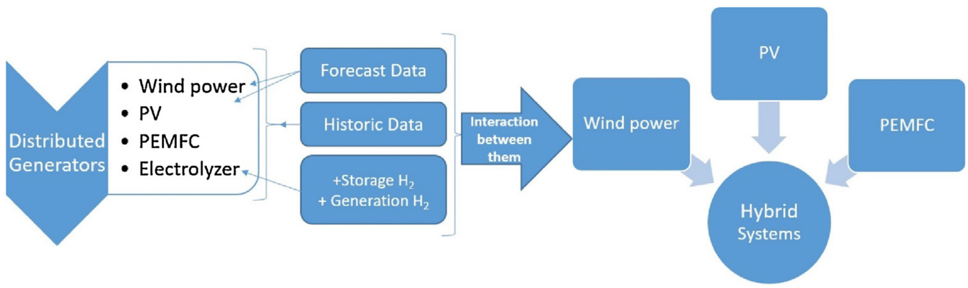

Fig. 1. Block diagram of the hybrid system.

use of wind and solar generation forecast as an input of a model predictive control, to track the load curve or final user's required power. The result is a proposed Advanced EMS to reduce and overcome the frequency affectation in hybrid systems based on renewable power generation. The proposed AEMS provides the liberty to handle the output power of the hybrid system considering the system boundaries without disturbing the network frequency. This approach makes the hybrid system (HS) a semi-dispatchable energy system even though it is built up of variable generation.

Contrary to other studies, a semi-dispatchable energy system with intermittent primary sources, able to manipulate the output power of the HS within physical boundaries is proposed.

2. Hybrid system modelling

The elements and models required for designing the hybrid system, which integrates the physical generators and the mathematical algorithm in order to forecast by using historic wind and radiation data from Mexico City, are presented in Fig. 1. The main idea is to combine the above elements so that the HS will be a reliable system. The forecast algorithm is implemented to the energy sources (wind speed and sun radiation) to be considered alongside the hydrogen behaviour, into the model predictive control (MPC), with the purpose of taking into account the predicted shortfall of the main energy sources, proceeding in the activation of the fuel cell supply to meet the power required by the final user. This section presents the individual models in the HS.

2.1. Relationship active power-frequency

The power generation-load balance of the system gives the frequency stability in a power system; any unbalance will affect the frequency. The primary power-frequency control for conventional generators is given by

$$P_{\text{act}} = P_{\text{sched}} - \frac{1}{R}(f_{\text{act}} - f_0) \tag{1}$$

where f_0 is the nominal frequency of the power system, f_{act} the actual frequency and P_{act} represents the currently produced active power. The power setting P_{sched} for each generator is the amount of power that the generator owner agreed to produce in accordance to its bid on the electricity market. The droop setting R determines the steady-state frequency drops with an increase in the consumption [1].

The presence of DG does not create great variations in power in a timescale of minutes, where the primary control works. An indirect consequence of a large-scale amount of DG is that there will be less conventional generation available for providing the primary reserve and the primary control.

Any loss of primary reserves should be made up by the secondary reserves. The reduction in secondary reserves will be made up from the tertiary reserves, which cover all timescales from 15 min onward. The transmission system operator starts new production units or changes the set points of units already in operation to accommodate for any depletion of primary and secondary reserves.

In a timescale of hours, DG provides the largest variations in production [1]. The unpredictability of the production is what matters to the transmission system operation.

2.2. Forecast model

It is important to mention that the energy forecasting models have become an important tool for dispatch planning and market operation; these help predict the power generation. A recursive least square (RLS) with forgetting factor method has been applied to forecast wind power and radiation in a short-term range of 1 h ahead with a 10 min data resolution [19].

The k-step AR(ρ) model with the standard notation using X as the regressor vector can be written like

$$Y_{t+k} = X_t^T \hat{\theta}_t + \epsilon_{t+k}. \tag{2}$$

RLS with a forgetting factor is based on the AR process and allows the parameter vector θ to change over time. For the weighted least squares estimator, the weighted estimation is calculated as

$$\hat{\theta}_t = \hat{\theta}_{t-1} + R_t^{-1} X_{t-k}[Y_t - X_{t-k}^T \hat{\theta}_{t-1}] \quad \because \quad R_T = \lambda R_{t-1} + X_{t+k} X_{t-k}^T \tag{3}$$

where X_t is the regressor vector, θ_t is the coefficient vector and Y_t is the dependent variable at time t. The weights decay exponentially over time. The parameter λ is the forgetting factor, describing how fast historical data are weighted down and taking values in the range of 0.90–1 [20]. The weights are equal to

$$\omega(\Delta t) = \lambda^{\Delta t} \tag{4}$$

where Δt is the age of the data.

2.3. Photovoltaic model

A photovoltaic (PV) system is composed by several photovoltaic solar cells; each cell can generate 1-2 W, depending on the material used. The cell equivalent circuit for a crystalline type is described in Fig. 2.

The parameter R_s is the cell resistance, which represents the semiconductor material resistance. Moreover, R_p is the cell shunt resistance; this stands for losses caused by the leakage current [21]. From the cell circuit in Fig. 2, the output current I can be calculated as

$$I = I_{\text{pv}} - I_o\left[\exp\left(\frac{V + R_s I}{V_t \alpha}\right) - 1\right] - \frac{V + R_s I}{R_p} \quad \because \quad V_t = \frac{k_{\text{pv}} T}{q} \tag{5}$$

where k_{pv} is Boltzmann's constant, q is the electronic charge, T is the

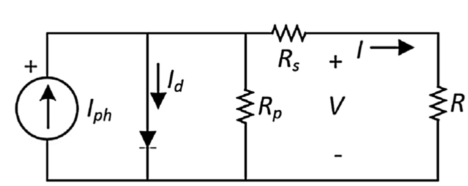

Fig. 2. Cell equivalent circuit.