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Improved frequency dynamic in isolated hybrid power system using an intelligent method

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ABSTRACT

The Isolated Hybrid Distributed Generation (IHDG) studied in this paper is consisted of a wind turbine generator and a diesel engine generator. The equivalent inertia of power grid reduces by increasing influence of variable speed wind turbines in power systems. Consequently, when a disturbance occurs in the power system the frequency fluctuations increases. To overcome this problem, a supplementary control loop is added to the converter of the variable speed wind turbine in order to share the inertia of the turbines in the power grid. But the appropriate rate of this contribution depends on the amount of load and must be suitably changed based on the load. In this paper, a Takagi–Sugeno (T–S) fuzzy system is designed to determine the contribution coefficient of variable speed wind turbine in such a way that variable wind turbine shares the maximum value of its inertia to compensate the reduced production in the power grid. However, the turbine does not pass its minimum speed limit while sharing the maximum value of inertia in the grid and prevents the cause of another disturbance in the power grid. In the proposed method, first, by using Particle Swarm Optimization (PSO) algorithm, the optimal values of contribution coefficient of wind turbines are attained proportional to the load in such a way that the minimum speed constraint is not violated. In the next stage, the initial T–S fuzzy system is extracted from the obtanied the optimal values of contribution by using subtractive clustering algorithm. In addition, Recursive Least Square (RLS) algorithm is used to adjust the consequent part of the T–S system. The efficiency of the proposed method is demonstrated through the simulation for different amount of load.

Introduction

The frequency stability is one of the most important issues in a power system which is determined by the balance between all production and consumption in the system. When a high power generator is out of the grid or a substantial load of power surges into the circuit, the balance between production and consumption is disturbed and cause changes in power system frequency. Generally, a power system responds to the load in three stages. The first stage is the inertial response of the synchronous generator which improves the dynamic frequency of the system in the first seconds of disturbance occurrence. In the second stage, the governor increases the input power of turbine to prevent the reduction of frequency and finally, a supplementary control loop changes the load reference point to stabilize the frequency at its nominal value [1].

The recent widespread usage of wind energy has called growing attention to wind turbines connected to Double-Fed Induction Generator (DFIG). These generators have attracted significant attention thanks to their feature in operating with variable speed wind. By increasing usage of this type of turbine-generators in power system, the contribution of synchronous generators reduces in the grid and the control frequency of the power system confronts greater challenges. Synchronous generators are naturally responded to the load fluctuations, but due to the use of electronic power convertors in variable-speed wind turbines, the rotation speed of generator is separated from the grid. Thus, the grid frequency variation is not observable in the generators rotors. Consequently, these power plants do not normally contribute to the frequency control of the grid and the frequency stability of the system is jeopardized [2,3].

Researchers have been done great efforts to resolve the challenges posed by the use of variable-speed wind turbines. In [2] and [3] a comparison is made between the inertia responses of DFIG and fixed-speed wind turbines during the frequency deviation of a

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power system. The results show that similar to the synchronous machines a fixed-speed generator can share its inertia in the grid; however, it is not true for DFIG. Therefore, a supplementary control loop has proposed for DFIG, which can increase the active power output of the system during the frequency disturbance.

Furthermore, it is observed that the released kinetic energy from the variable-speed wind turbine is greater than the kinetic energy released through the fixed-speed turbines. However, this method has some limitations such as the approximate value of its derivative function [4]. In [5], a study is carried out on the behavior and capacity of variable-speed wind turbines in generating extra active power immediately after a load disturbance. The results present that variable-speed wind turbines can share their power derived from its inertia for about 10 s in the grid. A supplementary control signal called inertia control was added to the active power control loop of the wind turbines for effective contribution of variable-speed wind turbine in adjusting the grid frequency. This loop is activated during the deviation of the grid frequency and by injecting a power greater than the wind turbine, which is derived from the kinetic energy stored in the rotating mass of its blades, improves the frequency dynamics of the power system in the early seconds after the occurrence of load disturbance. In general, the control inertia of a wind turbine can be categorized into two groups. In the first group, the extra amount of power is proportional to the frequency derivative [2,3]. In the second group, a control strategy is implemented to adjust the initial frequency of wind turbine. In this case, the provided additional power is proportional to the difference between nominal and measured frequency [6].

In [7], a combination of two control strategies proposed for producing the inertial response of wind turbines. In this method, an additional control signal which is proportional to the deviation and frequency deviation is used to increase the power of the wind turbine. Another method used for controlling the frequency of the variable-speed wind turbine is de-loading. In this technique, the frequency adjustment is done by changing the angle of blades in the wind turbine. In this case, the variable-speed wind turbine operates approximately near to its maximum power. In the first moments after the load disturbance and also drop in system frequency, the wind turbines are able to inject greater power into the grid by altering the angle to absorb the maximum wind power. In this technique, wind turbines have the capability to adjust frequency for long-term condition [8,9].

Takagi–Sugeno and Kang (TSK) fuzzy systems are useful tools for modeling the expert knowledge in order to control and describe the nonlinear systems with unknown dynamics [10]. In TSK system, the antecedent (*IF*) part of *IF-THEN* rules is the same as typical fuzzy systems (Mamdani), but the consequent part (*THEN*) is a linear combination of input variables. As a result of this modification, TSK fuzzy system provides a more detailed description of a complex system in comparison with other learning algorithms [11].

The knowledge base of a fuzzy system can be built based on expert knowledge or even input–output data pairs. However, the former is less accurate than the latter in terms of performance [12]. In order to extract fuzzy rules from input–output data pairs, a variety of techniques such as Kohonen neural networks and fuzzy clustering method proposed [13,14]. In this paper, subtractive clustering algorithm is used to extract fuzzy rules [15].

In this paper to improve the frequency dynamics of the power system, supplementary frequency control loops are added to power electronic converters to share the inertia of these turbines in power grid. In addition, a TSK fuzzy system is designed to absorb the maximum inertia in variable-speed wind turbines and prevent excessive speed reduction of the turbine, which causes turbine exit from the grid. TSK fuzzy system determines the contribution coefficient of wind turbine in a way that after the occurrence of disturbance, wind turbines share the maximum inertia to compensate the reduced generation in the grid meanwhile they do not violate the minimum speed limit.

Particle Swarm Optimization (PSO) is used to determine optimal input–output data pairs to generate initial TSK fuzzy system. PSO algorithm searches and specifies the optimal contribution

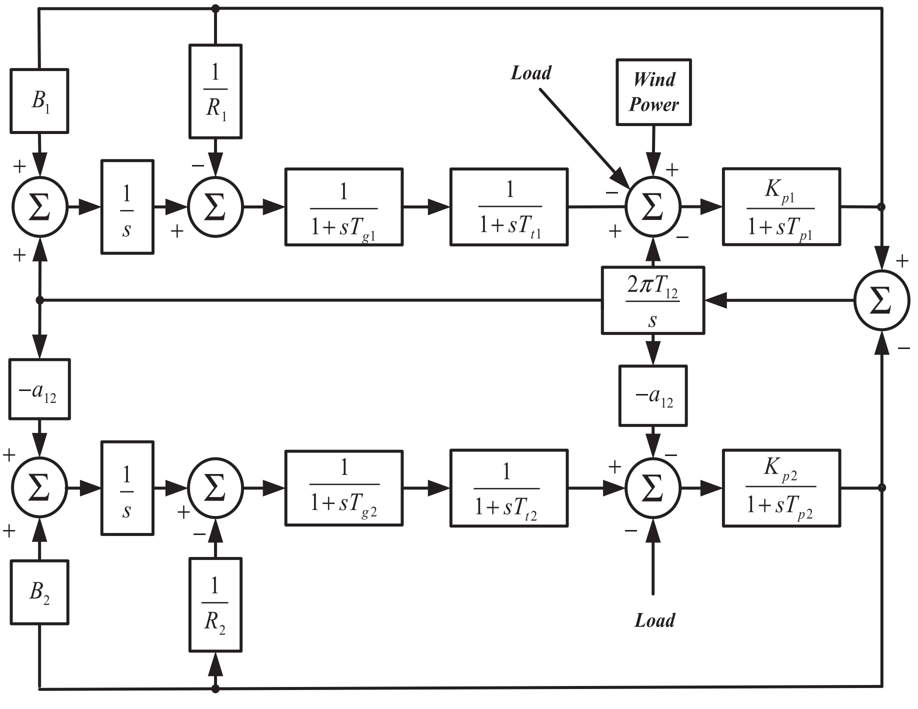

Fig. 1. A block diagram of a two-area power system with variable speed wind turbines.