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Effective active power control of a high penetration wind diesel system with a Ni–Cd battery energy storage

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ABSTRACT

High penetration (HP) Wind Diesel Hybrid Systems (WDHS) have three modes of operation: Diesel Only (DO), Wind Diesel (WD) and Wind Only (WO). The HP-WDHS presented in this article consists of a Wind Turbine Generator (WTG), a Diesel Generator (DG), the consumer Load, a Ni–Cd Battery based Energy Storage System (BESS), a discrete Dump Load (DL) and a Distributed Control System (DCS). The DG includes a friction clutch which allows the Diesel Engine (DE) to be engaged (DO and WD modes)/disengaged (WO mode) to the Synchronous Machine (SM). The DCS consists of a sensor node which measures the SM speed and active power, calculates the reference active power P_{REF} necessary to balance the active power in the WDHS and communicates this P_{REF} value through a message to the BESS and DL actuator nodes. In the WD mode both the DG and WTG supply active power to the system and the DE speed governor regulates the system frequency. However in an HP-WDHS the power produced by the WTG (P_T) can be greater than the one consumed by the load (P_L). This situation means a negative power in the DG (power inversion) with its speed governor unable to regulate frequency. To avoid this situation, the DCS must order coordinated power consumption to the BESS and DL in order to keep the DG produced power positive. In this article it is shown by simulation how the DCS manages both a temporary power inversion and a permanent one with the mandatory transition from WD to WO mode. The presented graphs for frequency, voltage, active powers of the system elements and battery voltage/current show the effectiveness of the designed control.

1. Introduction

A Wind Diesel Hybrid System (WDHS) is an autonomous electricity generating system using Wind Turbine Generators(s) (WTG) with Diesel Generator(s) (DG) to obtain a maximum contribution from the intermittent wind resource to the total produced power, while providing continuous high quality electric power [1]. The main goal with these systems is to reduce fuel consumption and in this way to reduce system operating costs and environmental impact. Direct addition of WTGs to a diesel powered grid does not result in substantial fuel saving as it can be expected. This is so because the diesel generators when being unloaded can consume fuel up to 40% of nominal consumption [2]. Therefore the fuel consumption saving is maximum with High Penetration (HP) WDHS, which are WDHS capable of shutting down the DGs during periods of high wind availability. HP-WDHS have three modes of operation: Diesel Only (DO), Wind Diesel (WD) and Wind Only (WO) [2]. In DO mode the DGs supply the active and reactive power demanded by the consumer load. Load sharing modules and speed governors controlling each diesel engine perform frequency regulation and voltage regulation is performed by the automatic voltage regulators in each synchronous machine. In WD mode, the WTGs also supply active power and the same regulators as in DO mode control the frequency and voltage. In WO mode the DGs are not running, only the WTGs are supplying active power and therefore auxiliary components such as Dump Loads (DL), Energy Storage Systems (ESS) and additional controls are needed to control frequency and voltage, as it will be seen in Section 2.

Dynamic simulation of WDHS has been focused mainly in the WD mode with different WDHS architectures. In [3] the interaction between one DG and one WTG without an energy storage system is studied; in [4] a WDHS with one DG, one WTG, a DL and a flywheel energy storage is simulated; in [5] the studied WDHS consists of several WTGs, two DGs and a superconducting magnetic energy storage. The simulation of the WO mode in a system consisting of one WTG, a Battery based energy storage and a DL is studied in [6]. The transition between the different operation modes has also been simulated. In [5] the disconnection of the WTGs from the isolated power system is simulated (WD to DO mode transition) and in [7] the connection of a WTG to the DG isolated grid is presented (DO to

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WD mode transition). In [8] the transition from WO to WD mode in a WDHS with a DG which includes a clutch is simulated.

One of the main goals of this article is to simulate the transition from WD to WO mode when the necessary conditions described in Section 2 are met. After this introductory Section 1, this article is organized as follows: Section 2 presents the HP-WHDS architecture discussed in this article along with its control requirements, Section 3 presents the control system that has been used, Section 4 shows the modelling of the WDHS components, Section 5 presents the WDHS response against different perturbations as well as the WD to WO transition simulation and Section 6 emphasizes the effectiveness of the presented control system.

2. The power system

The HP-WDHS discussed in this paper is presented in Fig. 1. The Synchronous Machine (SM) generates the voltage waveform of the isolated grid and its automatic voltage regulator controls the voltage to be within the prescribed levels during the three modes of operation, so the SM circuit breaker I_G must be permanently closed (I_G = ON in Fig. 1). The Diesel Engine (DE) provides mechanical power to the SM and in this article the DE speed control is isochronous, so the diesel speed governor will command the necessary fuelling rate to make the DE run at constant speed. The DG in Fig. 1 consists of the SM, the DE and a friction clutch, which has three states: engaged, locked and disengaged [9]. If the clutch is disengaged, the clutch frictional surfaces are not in contact and no torque is transferred from the DE to SM, so that if the WTG circuit breaker I_T is closed the operation mode is WO. In WO mode since the DE and SM axes are independent, the DE must not be running in order to save fuel. With the clutch engaged, the clutch frictional surfaces slip past one another and kinetic friction torque is transferred from the DE to the SM. Finally, if the clutch is locked, the frictional surfaces are locked together without slipping and static friction torque is transferred to the SM. With the clutch locked, the DE and SM turn at the same speed ($\omega = \omega_D$ in Fig. 1) and the WDHS is in the DO/WD mode if the WTG circuit breaker I_T is opened/closed respectively. In DO/WD modes, the DG under the control of the speed governor behaves as a controlled power source. Several real HP-WDHS include a clutch to transition from WO to WD modes and vice versa [10,11].

The WTG consists of a Wind Turbine (WT) driving an Induction Generator (IG) directly connected to the autonomous grid conforming a constant speed stall-controlled WTG (no pitch control). The WTG produced active power P_T depends among other factors on the cube of the wind speed [2] and since the WT used has no pitch control, there is no way to control the WTG active power, so it behaves as an uncontrolled source of active power. The IG consumes reactive power so a capacitor bank has been added to compensate the power factor.

The Dump Load (DL) consists of a set of semiconductor power switches and a binary bank of resistors. By closing/opening these power switches, the DL consumed active power can be controlled behaving as a controlled sink of active power. The Battery based Energy Storage System (BESS) consists of a battery bank and a power converter that interfaces the battery bank to the autonomous grid. The BESS can store or retrieve power as needed, so it behaves as a controlled sink/source of active power. The actuation of these controllable elements depends on the operation mode of the plant and will be explained later on.

In DO and WD modes the diesel speed governor controlling the DE, locked to the SM by means of the friction clutch, performs the frequency regulation by maintaining an instantaneous balance between the consumed and produced active power. Being P_{DE} the active power supplied by the DE, P_T the power supplied by the WTG (also called wind power), P_L the power consumed by the load, P_D the power consumed by the DL, P_S the power consumed/supplied by the BESS, J the DG inertia (sum of the DE + SM inertia) and ω the SM shaft speed, the power equation of the SM in WD mode is:

$$P_{DE} + P_T - P_L - P_D - P_S = J\omega \frac{d\omega}{dt} \quad (1)$$

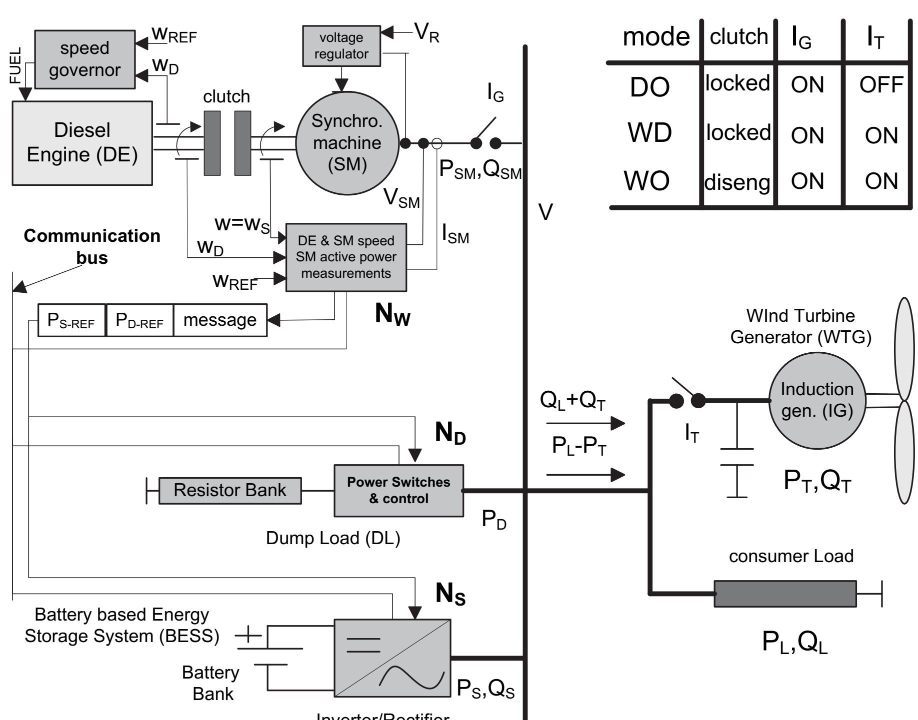

Fig. 1. Layout of the HP-WDHS and the DCS.