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Original Research Article

Voltage and frequency control of an autonomous hybrid generation system based on linear model predictive control

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ABSTRACT

This paper presents an adaptive control for voltage and frequency regulation of a stand-alone hybrid wind-diesel power system based on constrained linear model predictive control (MPC). The proposed system mainly consists of a wind turbine driving a self-excited induction generator (SEIG) connected via a DC link to a synchronous generator (SG) driven by a diesel engine. The SG is equipped with a voltage regulator and a static exciter. The wind generator and the synchronous generator together cater for the local load and power requirement. However, the load bus voltage and frequency are governed by the SG. To extract maximum available wind power, it is assumed that the wind generation system operates free without control. The control objective aims to control the load voltage and frequency. This is achievement via controlling the field voltage and rotational speed of the SG. The MPC controller is based on the minimization of a cost function of voltage and rotor speed errors while respecting the given constraints. The hybrid wind-diesel energy system with the proposed MPC has been tested through a turbulent and step change in wind speed and load impedance respectively. Simulation results show that accurate tracking performance of the system has been achieved.

Introduction

Various renewable sources are found at different geographical areas near to consumers. To obtain a reliable power supply system, integration of a continuously available power such as a diesel power generation and a non- conventional power generation are required. Such system are called isolated hybrid power systems. Using the hybrid power generation systems decreases the annual diesel fuel consumption and at the same time minimizes the level of pollution. To take full advantage of the available wind energy during the periods of time and to minimize the diesel fuel consumption, a proper control strategy has to be developed. Therefore, a proper control system has to be designed, subject to the specific constraints for a particular application. It has to maintain power quality, measured by the quality of electrical performance, i.e., both the voltage and the frequency have to be properly controlled [1].

Many control techniques have concerned with the voltage and/or frequency control of the hybrid wind-diesel generation system and achieving optimal output of the wind turbine. In some schemes, the hybrid wind-diesel power system uses compressed air energy storage with the wind-diesel hybrid system [2]. Other control schemes use static VAR compensators [3] or STCOM [4,5] for reactive power control.

Mathematical modeling of a typical hybrid system with PI controllers and system dynamic studies on it has been reported by Scott [6]. However, it is well known that the performance of the systems with fixed gain controllers designed on the fixed parameter model of the system does not stay optimal as the system parameters undergo a change.

Recently, advanced control techniques, which were applied successfully on the machine drives, have been proposed for regulating the isolated hybrid wind-diesel power system. They include Artificial neural networks [7], adaptive control based on a two level Energy storage systems [8], linear quadratic Gaussian control [9], adaptive fuzzy control [10] and vector control [11]. In these methods, the speed feedback may be necessary to avoid instability. Moreover, wind velocity information may be needed as well. Also, the key point of direct power schemes is a correct and fast estimation of the active and reactive power as well as fast PI controllers.

In recent years, A lot of literatures have been applied MPC in energy conversion [12–14]. The model predictive controller normally needs a significant computational effort. As the performance of the available computing hardware has fast increased and new rapid algorithms have been presented, it is now possible to apply MPC to command rapid systems with small time steps, as electrical drives.

In This paper, a controller design and simulations of a hybrid wind-diesel generation plant based on model predictive control are presented. This generation plant is conceived to supply electric

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Nomenclature

v_{ds}, v_{qs}	d–q stator voltages of induction generator
i_{ds}, i_{qs}	d–q stator currents of induction generator
i_{dr}, i_{qr}	d–q rotor currents of induction generator
R_s, R_r	stator and rotor resistances per phase of induction generator
L_s, L_r, L_m	stator, rotor and magnetizing inductances of induction generator
C_0	self-excitation capacitance per phase of induction generator
ω_s	angular stator frequency of the induction generator
ω_m	angular rotor speed (electrical rads/s) of the induction generator
J	moment of inertia
f	friction coefficient,
p	differential operator d/dt
L_{DC}	DC-link inductance
R_{DC}	DC-link resistance
α_R, α_I	firing angles of the converter and inverter
v_{dcon}, v_{qcon}	d–q input voltage of the converter
i_{dcon}, i_{qcon}	d–q input current of the converter
i_{dl}, i_{ql}	d–q rectifier input currents
i_{dc}, i_{qc}	d–q capacitor currents of the SEIG.
I_{DC}	DC-link current
v_{inv}	inverter output voltage
v_q^r, v_d^r	d–q stator voltages of synchronous generator
$v_{kd}^r\, v_{kq}^r$	d–q damper winding voltages of synchronous generator
v_f^r	field winding voltage of synchronous generator
i_d^r, i_q^r	d–q stator currents of synchronous generator
i_{kd}^r, i_{kq}^r	d–q damper winding currents of synchronous generator
i_f^r	field winding current of synchronous generator
R_s	stator resistance of synchronous generator
R_{kd}, R_{kq}	d and q damper winding resistances
L_{md}, L_{mq}	d and q mutual inductances
L_d, L_q	d and q self inductances
ω_{sg}	rotor speed (electrical rads/s) of the synchronous generator
T_{md}	torque input from diesel engine
φ_r, φ_f	applied and actual fuel flow rate of diesel engine
τ_1	combustion delay time constant
τ_2, K_2	time constant and gain of fuel rack position actuator
N_p	prediction horizon.
N_c	control horizon.
u	vector Control inputs
u_{MD}	vector of measured disturbances
WT	wind turbine
λ	tip speed ratio
β	blade pitch angle
C_p	power coefficient
A	swept area
ρ	air density
R	wind turbine rotor radius
ω_t	the mechanical angular rotor speed of the wind turbine.
T_m	wind turbine output torque
V_w	wind speed

power to an isolated load not connected to the electrical network. The main power generation system consists of a wind turbine driving a self-excited induction generator connected via an asynchronous AC–DC–AC link to a SG driven by a diesel engine. The SG is equipped with automatic voltage regulator and a static exciter. The wind generator and the synchronous generator together feed the local load.

The proposed hybrid wind diesel energy scheme with the proposed controller has been tested through a turbulent change in wind speed and a step change in load impedance. Simulation results show that there is accurate tracking performance of the proposed hybrid wind diesel power system.

System description

Fig. 1 shows a hybrid wind-diesel power system supplying an autonomous load. This system essentially consists of a self-excited induction generator (SEIG) driven by wind turbine connected via an uncontrolled rectifier-inverter (AC–DC–AC) system to a synchronous generator (SG) driven by a diesel engine. The synchronous generator is equipped with a voltage regulator and a static exciter. The wind generator and the diesel generator together supply the isolated load power requirement.

System dynamic model

The dynamic models of the different parts of the system can be described as follows:

Diesel side dynamic model

Diesel generation side system consists of diesel engine, synchronous generator and the load which can modeled as following:

Synchronous generator dynamic modeling

The dynamic mathematical model of the synchronous generator in the d^r–q^r axis synchronously rotating reference frame fixed in the rotor (i.e., d^r–q^r reference frame rotating at the rotor speed ω_{sg}) is given by [15]:

$$pi_q^r = \frac{L'_{kq}}{(L'_{kq} - L^2_{mq})}\left[-R_s i_q^r - \frac{L'_{kq}L'_{mq}}{L'_{kq}} i_{kq}^{r'} - \omega_{sg} i_d^r + \omega_{sg} L_{md} i_{kd}^{r'} + \omega_{sg} L_{md} i_f^{r'} - V_q^r\right] \quad (1)$$

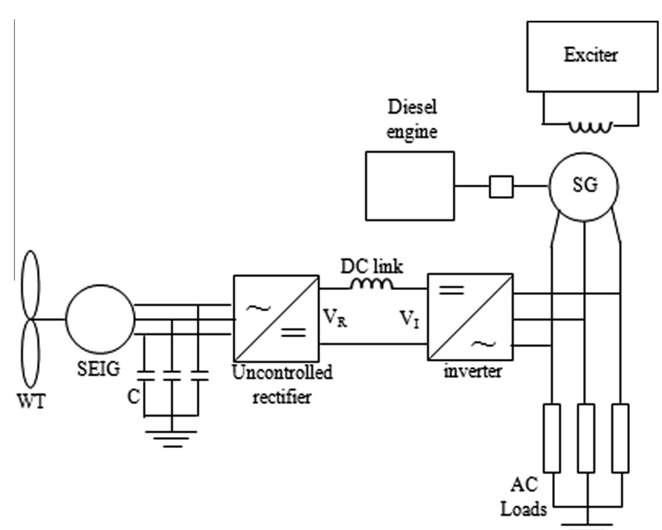

Fig. 1. Block Schematic diagram of the proposed hybrid wind-diesel-generation system.