

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.

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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 systems 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_{di}, i_{qi} 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, v'_d d - q stator voltages of synchronous generator
 v'_{kd}, v'_{kq} d - q damper winding voltages of synchronous generator
 v'_f field winding voltage of synchronous generator
 i'_d, i'_q d - q stator currents of synchronous generator

i'_{kd}, i'_{kq} d - q damper winding currents of synchronous generator
 i'_f 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]:

$$p i_q^r = \frac{L'_{kq}}{(L'_{kq} - L'^2_{mq})} \left[-R_s i_q^r - \frac{L'_{kq} L'_{mq}}{L_{kq}} i_{kq}^{r'} - \omega_{sg} i_d^r + \omega_{sg} L_{md} i'_{kd} + \omega_{sg} L_{mq} i'_{kq} - V'_q \right] \tag{1}$$

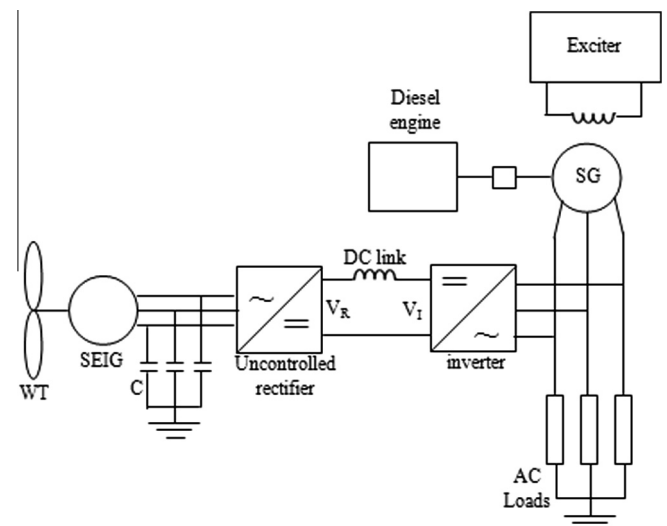


Fig. 1. Block Schematic diagram of the proposed hybrid wind-diesel-generation system.

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