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Power balance control of micro gas turbine generation system based on supercapacitor energy storage

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ABSTRACT

In view of the impact load problems in the traditional micro gas turbine (MT) power generation system, this paper analyzes its working mechanism and finds the reason lies in the slow response of the micro turbine output power adjustment. In order to make up for the shortage of the instantaneous output power of micro turbine, the method of instantaneous power fast control is proposed. Control algorithm of instantaneous compensation power is raised by power response prediction of MT. The high power dynamic response of super-capacitor energy storage can compensate low dynamic response problem of MT output power, so the instantaneous power of the system is real balance to ensure that the DC bus voltage is smooth and adaptability of MT power generation system is enhanced for impact load. Finally, the correctness and feasibility of the proposed control strategy are verified by simulation results.

1. Introduction

With the rapid development of human society, the demand for energy power is increasing, and it is very important to improve the performance and energy efficiency of the power system. MT has the characteristics of high power density [1], high reliability, high efficiency [2], low maintenance and low emissions [3]. It can use natural gas, diesel, oil field associated gas and other fuels that does not rely on a single energy form [4]. In the aerospace, defense and other industries, such as ships, oil and gas production and other fields it has a wide range of applications, highly valued in recent years.

The impact load is generally present in distributed generation systems, which are related to the finite energy of distributed or independent generation system. For example, impact load cycling has been identified as being one of the main causes of fuel cell inefficiencies as a consequence of compressor inertia and gas manifolding effects [5]. For a constant speed wind turbine in an electrical network torque impact can lead to various active power quality, reactive power and r.m.s. phase to phase voltage problems [6]. Another example is solar energy source claimed as a clean and noise free source of electricity. Even so, a reliable energy storage system is required as an energy buffer to bridge the mismatch between available and required energy [7]. In order to meet the impact load, the MT generation system must have the ability of fast adjustment of output power. However, the response of output mechanical power is slow because of slow MT combustion mechanism. This slow response characteristic cannot suit to the application object with impact load. Therefore, the development and popularization of MT generation system is restricted [8]. In order to solve this problem, it is needed to analyze the variation of MT output power in theory, and to further study and propose the solution based on instantaneous power balance.

An effective method to solve the impact load problem is to compensate for the slow response of the original motive output power by using the fast charge and discharge energy storage device. Supercapacitor has the advantages of long service life [9], high charge and discharge efficiency [10], short charge and discharge time and so on [11], which has been widely used in many applications such as wind generation system [12], fuel cell [5], electric vehicle [13] and battery energy storage system [14] mainly to solve the dynamic response problem. The corresponding coordinated control strategy can be divided into two types, one is based on the accurate information of the output power, and the other is not to need the exact information. Because of the easy to implement and no need to know detailed output characteristic, the methods of PI control [15], droop control, low pass filter [16], high pass filter and so on are widely used for smoothing the output power of the

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Nomenclature

η_B	combustion efficiency
η_c	efficiency of compressor
η_{MT}	MT efficiency
η_t	efficiency of turbine
$\lambda_{k1,k2,k3}$	MT closed loop poles
ω_{dc}	PWM rectifier voltage loop corner frequency
ω_i	inverter current loop cut-off frequency
ω_p	PWM rectifier power loop cut-off frequency
ω_{SCc}	supercapacitor energy storage unit open loop cut-off frequency
ω_v	inverter voltage loop cut-off frequency
π_c	pressure ratio of compressor
π_t	expansion ratio of turbine
A	MT system matrix
$a_{ij} i,j = 1,2,3$	MT system matrix coefficients
B	MT input matrix
$b_i i = 1,2,3$	MT input matrix coefficients
C	DC bus capacitor
C_f	inverter output filter capacitor
C_{MT}	MT output matrix
G_c	mass flow of compressor
G_f	mass flow of fuel
$G_{inv}(s)$	inverter Transfer function
$G_{MT}(s)$	microturbine Transfer function
$G_{rec}(s)$	PWM rectifier Transfer function
G_t	mass flow of turbine
$i_{f\alpha}, i_{f\beta}$	inverter output current in two phase stationary coordinate
i_{fa}, i_{fb}	inverter output current in three phase stationary coordinate
i_{fref}	inverter output current set value
i_f	inverter output current
i_L	load current
i_{SC}	supercapacitor current
K	MT feedback matrix
$k_i i = 1,2,3$	MT feedback matrix coefficients
K_{dci}	PWM rectifier voltage loop integral gain
K_{dcp}	PWM rectifier voltage loop proportional gain
K_{dc}	supercapacitor energy storage unit system gain
K_{ifi}	inverter current loop integral gain
K_{ifp}	inverter current loop proportional gain
K_{pi}	PWM rectifier power loop integral gain
K_{pp}	PWM rectifier power loop proportional gain
K_{SCi}	supercapacitor energy storage unit power loop integral gain
K_{SCp}	supercapacitor energy storage unit power loop proportional gain
K_{vfi}	inverter voltage loop integral gain
K_{vfp}	inverter voltage loop proportional gain
L_{dc}	supercapacitor energy storage unit output filter inductance
L_f	inverter output filter inductance
L_g	synchronous inductance of permanent magnet synchronous motor
n	speed
P_1	Inlet total pressure of compressor
P_2	outlet total pressure of compressor
P_3	input pressure of turbine
P_4	output pressure of turbine
P_c	consumption power of compressor
P_{ESSdc}	DC side power of supercapacitor energy storage unit
P_f	input power of MT
P_{Ldc}	DC side power of load
P_L	load active power
P_m	output power of MT
P_{rec}	output power of PWM rectifier
P_{SC}	supercapacitor output power
P_t	output power of turbine
Q_L	load inactive power
Q_u	low heat value of fuel
R_{dc}	supercapacitor energy storage unit output filter resistance
R_f	inverter output filter resistance
R_g	stator winding resistance of permanent magnet synchronous motor
S_a, S_b, S_c	supercapacitor converter ratio
T_1	inlet temperature of compressor
T_2	output temperature of compressor
T_2'	temperature of cold outlet end
T_3	input temperature of turbine
T_4	output temperature of turbine
T_4'	temperature of hot outlet end
T_{SC}	supercapacitor energy storage unit power sampling filter time constant
v_{dcref}	DC bus voltage set value
$v_{f\alpha}, v_{f\beta}$	inverter output voltage in two phase stationary coordinate
v_{fa}, v_{fb}	inverter output voltage in three phase stationary coordinate
v_{fref}	inverter out voltage set value
v_f	inverter output voltage
v_{SC}	supercapacitor voltage
*	refers to the stagnation parameter

generation system [17]. The difficulty of these methods lies in the choice of the control strategy and the design of the controller, which needs to achieve the maximum power output of the generation system and smooth the output power. These methods are passive response control strategies, so the control response is slow, and the power distribution between the prime generation equipment and the energy storage is not easy to achieve optimization.

In this paper, the supercapacitor energy storage is applied to the MT generation system, and for impact load compensation the instantaneous power fast control method is proposed. Control algorithm of instantaneous compensation power is raised by power response prediction of MT. The high power dynamic response of super-capacitor energy storage can compensate low dynamic response problem of MT output power, so the instantaneous power of the system is real balance to ensure that the DC bus voltage is smooth and adaptability of MT power generation system is enhanced for impact load. The control strategy is proposed based on the characteristics of the MT output power, which has faster response, better power distribution between prime generation system and energy storage.

The remainder of this paper is organized as follows. In Section 2, the structure of MT generation system is analyzed. In Section 3, MT model is established and output characteristics is analyzed. In Section 4, instantaneous power compensation control is proposed, witch is validated in Section 5, and conclusions are drawn in Section 6.