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Frequency control in micro-grid power system combined with electrolyzer system and fuzzy PI controller

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Abstract

The widespread use of various kinds of distributed power sources would impact the quality of the power supply within a micro-grid power system, causing many control problems. This paper focuses on the stability of micro-grid operation and discusses the control techniques of combining a micro-turbine with the fuel cell and electrolyzer hybrid system to expand the micro-grid system's ability to solve power quality issues resulting from frequency fluctuations. The paper examines the feasibility of fuel cell and electrolyzer hybrid system control, especially dynamic control of an electrolyzer system, to secure a real power balance and enhance the operational capability of load frequency control. The proposed control and monitoring system can be considered to be a means of power quality control, both to improve the frequency fluctuations caused by random power fluctuations on the generation and load sides and to relax tie-line power flow fluctuations caused by frequency fluctuations in the interconnected micro-grid power system.

Keywords: Power quality control; Micro-grid; Electrolyzer system; Fuzzy PI controller; Renewable energy

1. Introduction

Although the idea of effective renewable energy use as a means of coping with environmental and resource problems, especially of reducing CO_2 emissions, is globally attractive, inappropriate application of distributed generation power supply systems can be a cause of insecure power supply. The micro-grid is one such system, consisting of distributed generators, loads, power storage devices and heat recovery equipment, among other components [1–3]. The main advantages of the micro-grid system are that (1) it can be operated independently from conventional utility grids, (2) it can make use of power and heat sources collectively, (3) it can be interconnected to the utility grids at one point.

In this paper, a micro-grid system (see Fig. 1) comprised of a control and monitoring system, a micro-turbine, a housing load, a load-controllable electrolyzer system to manufacture hydrogen, a hydrogen tank and renewable-energy-utilizing generators such as 100 kW wind power (WP), 25 kW photovoltaic (PV), 5 kW proton exchange membrane fuel cell (FC), and others, is considered. We assume that the power supply–demand balance control of the micro-grid system is performed by the control and monitoring system through a control area network (CAN) composed communication network. Moreover, the electricity of electrolyzer system is supplied mainly by the wind power and photovoltaic energy sources and the hydrogen produced by the electrolyzer system is stored in the hydrogen tank to be converted back to electricity in the proton exchange membrane fuel cells. The wind power is considered as primary source. However, considering the lack of power supply from renewable power sources, a micro-turbine is implemented to supply the base load containing the electrolyzer system and the housing load. A 100 kW micro-gas turbine is considered and it is assumed that the fuel for this turbine is supplied independently by a micro-gas turbine system.

Wind and photovoltaic generators have the disadvantage of an unstable power output. Therefore, in these kinds of hybrid small-scale power systems, a sudden real power imbalance or a large frequency fluctuation can easily occur, and reducing such fluctuations by the sole means of applying the dynamic control

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Nomenclature

Base	base capacity of micro-grid system
CAN	control area network
CMD	command
$dP_{Housing}$	standard deviation for housing real power
dP_{WP}	standard deviation for wind power output
dP_{PV}	standard deviation for PV output
D	damping coefficient
E	error
EC	error change
ES	electrolyzer system
Δf	frequency fluctuation
f_0	system frequency
FC	fuel cell
FPI	self-organizing fuzzy PI
K_E	quantificational gain for error
K_{EC}	quantificational gain for EC
K_{ES}	gain for ES
K_{FC}	gain for FC
K_I	integral gain
K_{MT}	droop property of MT output
K_P	proportional gain
ΔK_I	change in K_I
ΔK_P	change in K_P
M	inertia constant
MT	micro-turbine
NB	negative big
NM	negative medium
NS	negative small
PB	positive big
PEM	proton exchange membrane
PM	positive medium
PS	positive small
PV	photovoltaic
P_{ES}	load power of ES
P_{FC}	FC power output
$P_{Housing}$	load power of housing
P_{MT}	MT power output
P_{tie}	tie-line power
$P_{tie-ref}$	Scheduled P_{tie}
P_{WP}	wind power output
P^G	generated real power
P^L	system load
P_{ES}^{ini}	initial ES load power
P_{FC}^{ini}	initial FC output
$P_{Housing}^{ini}$	initial housing load
P_{MT}^{ini}	initial MT output
P_{PV}^{ini}	initial PV output
P_{WP}^{ini}	initial WP output
ΔP	real power imbalance
ΔP_{ES}	change in ES load
ΔP_{FC}	change in FC output
ΔP_{MT}	change in MT output
ΔP_{-ref}	expected ΔP in micro-grid
ΔP_{tie}	difference between P_{tie} and $P_{tie-ref}$
T_{ES}	time constant of ES
T_{FC}	time constant of FC
WP	wind power
X_{tie}	tie-line reactance
ZO	zero

Greek symbol

θ	relative phase angle between utility grid and micro-grid

of a micro-turbine is sometimes ineffective. Moreover, when the type of power line designed to be interconnected to a utility grid is 380 V three-phase AC line, applying a DC or AC source to the AC grid would lead to harmonic distortion of voltages and currents [4]. Thus, the widespread use of various kinds of distributed power sources would impact the quality of the power supply within the micro-grid, causing many control problems. Here, we have ignored the harmonics resulting mainly from the operation of power electronic systems (e.g. converters) and studied the frequency fluctuations resulting mainly from real power imbalances.

The so-called hydrogen economy is a long-term project that can be defined as an effort to change the current energy system to one which attempts to combine the cleanliness of hydrogen as an energy carrier with the efficiency of fuel cells as devices to transform energy into electricity and heat. As an energy carrier, hydrogen must be obtained from other energy sources, in processes that, at least in the long-term, avoid or minimize CO_2 emissions [5]. Electrolyzer system fed by renewable energies (such as photovoltaic solar panels or windmills) or biomass reformers is the distributed resource of interest to generate hydrogen.

A HOGEN® electrolyzer system [6] is considered in this paper. The power consumption of this system can be controlled in the millisecond level by adjusting the pressure in the customer piping system. This pressure control can be realized by means of a control and monitoring system operated

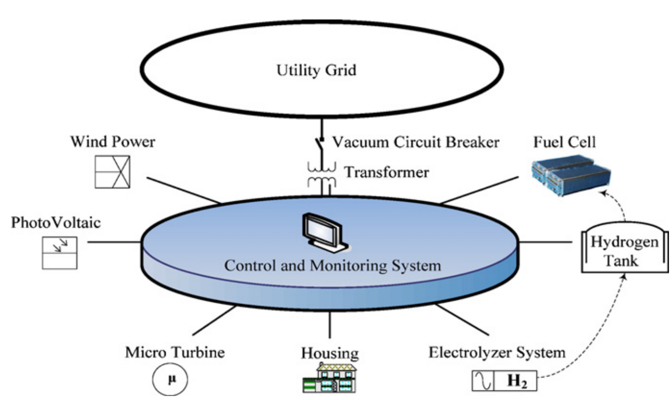

Fig. 1. System configuration of micro-grid network.