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Enhancement of micro-grid performance during islanding mode using storage batteries and new fuzzy logic pitch angle controller

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ABSTRACT

Power system deregulation, shortage of transmission capacities and needing to reduce green house gas have led to increase interesting in distributed generations (DGs) especially renewable sources. This study developed a complete model able to analysis and simulates in details the transient dynamic performance of the Micro-Grid (MG) during and subsequent islanding process. Wind speed fluctuations cause high fluctuations in output power of wind turbine which lead to fluctuations of frequency and voltages of the MG during the islanding mode. In this paper a new fuzzy logic pitch angle controller is proposed to smooth the output power of wind turbine to reduce MG frequency and voltage fluctuations during the islanding mode. The proposed fuzzy logic pitch controller is compared with the conventional PI pitch angle controller which usually used for wind turbine power control. Results proved the effectiveness of the proposed fuzzy controller in improvement of the MG performance. Also, this paper proposed using storage batteries technique to reduce the frequency deviation and fluctuations originated from wind power solar power fluctuations. Results indicate that the storage batteries technique is superior than fuzzy logic pitch controller in reducing frequency deviation, but with more expensive than the fuzzy controller. All models and controllers are built using *Matlab® Simulink®* environment.

1. Introduction

Now days, power system deregulation and liberalization of electricity markets in many countries are changing the face of electricity generation and transmission systems or networks [1,2]. Reduction CO_2 emissions in electricity generation field, recent technological developments in micro generation domain in addition to electricity business restructing are the main factors responsible for growing interest in using micro generations [3,4]. In fact, connecting small generation units (micro sources) with power rating less than a few tens of kilo Watts to low voltage (LV) networks potentially increases the reliability for end-users [5,6]. It brings additional benefits for global system operation and planning regarding investment reduction for future grid reinforcement and expansion [7]. In this context, a MG can be defined as a low voltage network (e.g. a small urban area, a shopping center, or an industrial park) with its loads and several small modular generation systems connected to it, providing both power and heat (CHP) to local loads. The MG is intended to operate in the following two different conditions [8]:

- *Normal interconnected mode*: MG is connected to a main grid (distribution network); either being supplied or injected some amount of active power into the main grid.
- *Islanding mode*: MG operates autonomously, in a similar way to a physical island, when disconnection from the upstream distribution network occurs due to high disturbance occurrence in main grid.

Development of MG can contribute to emission reduction and mitigation of climate change. This is because available and currently developing technologies for distributed generation units are based on the renewable sources and the micro sources that are characterized by very low emissions [9]. New micro sources technologies (e.g. micro gas turbines, fuel cells, photovoltaic panels and several kinds of wind turbines) used in MG are not suitable for supplying energy to the MG directly. They have to be interfaced with the MG through inverters. Thus, use of power electronic interfaces in the MG leads to a series of challenges in design and operation of the MG [10]. Technical challenges associated with the operation and control of the MG are immense. In order to have a stable operation during network disturbances, maintaining stability and power quality during islanding mode require more sophisticated inverter control strategies for providing stable frequency and voltage in presence of arbitrarily varying loads.

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Nomenclature

MG	micro-grid
LV	low voltage
CHP	combined heat and power
PV	photovoltaic
FLC	fuzzy logic controller
PI	proportional integral
SSMT	single shaft micro turbine
SOFC	solid oxide fuel cell
VSI	voltage source inverter
P	active power (W)
Q	reactive power (Var)
P_m	mech. output power of wind turbine (W)
C_P	performance coefficient of wind turbine
v_{wind}	wind speed (m/s)
A	turbine swept area (m^2)
u_{sd}	d axis stator voltage (p.u)
i_{sd}	d axis stator current (p.u)
u_{sq}	q axis stator voltage (p.u)
i_{sq}	q axis stator current (p.u)
r_s	stator resistance (p.u)
r_r	rotor resistance (p.u)
i_{rd}	d axis rotor current (p.u)
i_{rq}	q axis rotor current (p.u)
P_{IG}^{Ref}	pitch controller input power command
AVG	average
SMA	simple moving average
EMA	exponential moving average
$\bar{P}_{mWT}$	average of wind turbine captured power
$P_{mWT\sigma}$	standard deviation of wind capture power
K_e	fuzzy logic controller error scale factor
$K\Delta e$	error difference scale factor
K_β	pitch angle scale factor
NL	negative large
NM	negative medium
NS	negative small
ZO	zero
PS	positive small
PM	positive medium
PL	positive large

Greek symbols

β	blade pitch angle (deg)
ω	angular speed (p.u)
λ	rotor blade tip speed to wind speed ratio
ρ	air density (kg/m^3)
ω_0	base angular electrical frequency
ψ_{sd}	d axis stator flux (p.u)
ψ_{rd}	d axis rotor flux (p.u)
ψ_{sq}	q axis stator flux
ψ_{rq}	q axis rotor flux (p.u)
ω_r	rotor speed (p.u)
T_e	electromagnetic torque (p.u)
β_{cmd}	pitch angle command signal

1.1. General overview of MG dynamics

Lopes et al. in [8] described the feasibility of control strategy adopted for operation of the MG when it becomes isolated. In [9], Kanellos et al. studied about the MG during both connected and islanded modes of operations. In [10], Barsali et al. presented control techniques for the DG to improve the continuity of electricity supply. Katiraei et al. in [11] investigated about the preplanned switching events and fault events that lead to islanding of the MG. Feasibility study of a MG islanding mode concept was laboratory tested in a prototype installed in the National Technical University of Athens (NTUA) which compromises a photovoltaic (PV) panel, a storage battery and loads. This prototype MG is connected to a low voltage grid [12]. In [13,14], the behavior of micro sources connected to distribution networks has been addressed. Peças Lopes et al. in [15], presented identification of control and management strategies for LV unbalanced MGs with plugged-in electric vehicles. In [16], Shahnia et al. discussed the operation and control of a hybrid MG containing unbalanced and nonlinear loads. In [17], Alsayegh et al. discussed the challenges and proposed management schemes concerned with grid connected renewable energy sources. Kaldellis in [18] proposed using autonomous electrical networks which consists of renewable energy resources and energy storage configurations for electrification of the remote villages and islands. Also, Kaldellis et al. in [19] used wind-hydro MG as a solution for remote islands electrifications. De Paepe et al. in [20] used micro combined heat and power (CHP) for residential applications.

All the previous mentioned references and other works available in the literature deal with dynamic performance of the MGs subsequent to islanding process. However, they do not consider the effects of wind speed fluctuations in the dynamic performance of the MG especially following the islanding occurrence. Until now, no work available in the literature proposed any technique or controller to smooth or reduce the fluctuations of the wind power installed in MG especially during the islanding mode. The main target of this manuscript to solve the problem of wind power fluctuation in the MG by employment fuzzy logic pitch angle controller and storage batteries.

The problems which may be originated by wind speed fluctuations during the islanding mode in the MG are:

- Fluctuations of MG frequency; as MGs frequency during islanding mode is controlled and governed by small energy storage source like flywheel or battery (slack bus) connected to power electronic inverter. The generated wind power is proportional to the cube of the wind speed; any variation in wind speed causes high fluctuations in the generated wind power, which must be compensated from the energy storage source.
- Amount of reactive powers absorbed by wind generators (induction generators) depends on the value of generated active powers. Therefore, variations in wind speed cause fluctuations in reactive powers absorbed by wind generators and lead to voltage flicker at all the MG's buses especially at the wind generator's bus.
- Frequency fluctuations and voltage flickers inside the MG during islanding mode originate instability problems and provide poor power quality especially for sensitive loads which cannot accept high voltage and frequency variations.

To solve the above mentioned problems regarding wind speed fluctuations and improvement of power quality inside the MG during the islanding mode, fluctuated wind power inside the MG must be smoothed. This paper deals with this duty. In this study, the following three issues are described:

(1) Developing a complete model which can describes about all MG's components (micro sources, inverter's control scheme, control strategies, storage devices, etc.) in details.
(2) Proposing a new fuzzy logic pitch angle controller for reducing fluctuations of output power of wind turbines.