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Hybrid and coordinated soft starting controller for wind generation system runs in the standalone Micro Grid

Rashad M. Kamel *

Electrical Engineering Department, College of Engineering and Petroleum, Kuwait University, P.O. Box 5969, Safat 13060, Kuwait
Electrical Engineering Department, Faculty of Engineering, Assiut University, Assiut, Egypt

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ABSTRACT

Low rating and individual characteristics of the Distributed Generators (DGs) make the standalone Micro Grid (MG) weak power system. When the standalone MG contains wind generation system, special care should be taken during the starting process of the wind generation system to avoid the MG instability. This study proposes a new soft starting controller to improve the starting process of the wind generation system. In the proposed controller, both the wind turbine blade pitch angle (mechanical) and the thyristor switches firing angles (electrical) are coordinated, and controlled simultaneously. The coordination aims to minimize and suppress the undesirable effects and consequences of the wind generation system starting on the standalone MG performance. With employing the proposed hybrid and coordinated controller, the wind generator starting current grows very slowly until it reaches its rated value. On the other side, without employing the proposed controller, the wind generator starting current suddenly jumps and exceeds 400% of its rated value. Also, without employing the proposed controller, the MG frequency drops to less than 49.3 Hz. In addition, the voltage at MG buses drops to 0.9 p.u. in absence of the proposed controller compared with 0.95 p.u. if the controller is employed. The novelty on the proposed controller is the coordination between the thyristor valve firing angle (electronic) and the wind turbine blade pitch angle (mechanical) to achieve the desired performance. The overall performance and the power quality of the standalone MG have been highly improved after employing the proposed coordinated hybrid soft starting controller.

1. Introduction

The starting process of the wind generation system has several consequences on the performance and the power quality of the power system [1–4]. The connection of wind turbine to the power system has an influence on voltage level, voltage flicker, and over current [5]. Several regulation factors must be considered before connecting the wind generation system to the weak power grid. The most important regulating factors for connecting the wind turbine with the power grid can be summarized as follows [6–8]:

1. Factor decides the peak current during the wind generation system starting process.
2. Factor considers the maximum voltage drop due to the wind generation system starting process.
3. The flicker step factor [1,4].
4. For weak and small power system such as the standalone MG, the maximum dropping on system frequency must be considered.

The standalone Micro grid (MG) is a weak power system. It includes low rating micro sources or Distributed Generators (DGs) such as photovoltaic, small wind turbines, fuel cell, micro turbines. In addition, the MG also contains one or more storage device such as batteries, flywheel, and super capacitors [9–11]. During the normal operating condition, the MG is connected with the main power grid (distribution power network). The main grid represents an infinite bus for the MG in the grid connected mode. If any fault or high disturbance occurs in the main grid, the MG will transfer to the islanding mode (standalone mode). During the standalone mode, the MG feeds its loads locally and it performs as a small, and a weak isolated power grid [12]. Existence of wind generation system in standalone MG requires special attention during the starting process to avoid the MG instability and black out mode.

For the fixed speed wind generation system, there are many controllers that have been proposed and designed in the literature for the purpose of soft starting. The typical soft starting controller

* Correspondence to: Tokyo University of Agriculture and Technology, Tokyo, Japan.
E-mail address: rmkamelm@gmail.com.

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Nomenclature

Acronyms

MG	Micro Grid
DGs	Distributed Generators
SOFC	Solid Oxide Fuel Cell
PV	Photovoltaic
PLL	Phase Locked Loop

Parameters

r	Rotor radius of wind turbine (m)
R_s	Generator stator resistance (Ω)
R_r^-	Generator rotor resistance (Ω)
X_s	Generator stator reactance (Ω)
X_r^-	Generator rotor reactance (Ω)
X_m	Generator magnetizing reactance (Ω)
A	Wind turbine rotor swept area (m^2)

Greek Symbols

α	Thyristor switch firing angle
β	Wind Turbine blade pitch angle
λ	Tip speed ratio
ω	Wind turbine radial speed (rad./s)
ρ	Air density (kg/m^3)

Variables

C_P	Performance coefficient of the wind turbine
f_{MG}	Standalone Micro grid frequency (Hz)
f_r	Induction machine rotor frequency (Hz)
I_s	Generator stator current (A)
I_r^-	Generator rotor current (A)
I_o	Generator no load current (A)
n_s	Synchronous speed (rpm)
n_r	Rotor speed (rpm)
P_{airgap}	Generator air gap power (W)
p	No. of generator poles
P_m	Mechanical output power of the turbine (W),
S	Machine slip (rpm or p.u.)
V_G	MG voltage at wind generator bus
V_s	Generator stator voltage (V)
V_W	Wind speed (m/s)

of the wind generation system consists of antiparallel thyristors which are short circuited by electromagnetic contactor once the starting process finishes [6,13]. The firing angle of the conventional soft starter switches (antiparallel thyristor) will be controlled to limit the wind generator starting current to the rated value. No other control signals are used to control and adjust the thyristor switches firing angle. One of the drawbacks of the conventional soft starting controller is absence of the coordination between thyristor firing angle and wind turbine blade pitch angle. In other words, there is no coordination between the electrical part (thyristor firing angle) and the mechanical part (wind turbine blade pitch angle). In this paper, high improvement is added to the conventional soft starting controller. The improvement is a coordination between the thyristor switches firing angle (electronic) and the wind turbine blade pitch angle (mechanical). In other words, the conventional controller becomes coordinated hybrid electromechanical soft starting controller. The proposed coordination between the thyristor switches firing angle and the wind turbine blade pitch angle has been designed to consider several limiting factors such as:

a. The starting current of the wind generator should not exceed the rated value. Also, the generator starting current should increase gradually with a very slow raising rate.
b. The voltages at all MG buses should not drop less than the certain acceptable level.
c. The dropping in the standalone MG frequency must stay far from the unstable and the unacceptable values.

The proper adjusting, adapting, and coordinating between the thyristor switches firing angle and the wind turbine blade pitch angle can guarantee and satisfy the regulating factors. Also, the suitable coordination verifies a good and a smooth starting and connection of the wind generation system to the standalone MG. No additional hardware is required to implement the proposed controller. The proposed controller only requires simple modification on the control algorithm of the thyristor firing angle and wind turbine blade pitch angle. This fact makes the proposed controller economically attractive.

All the previous publications which described the soft starting controllers, the system frequency and voltage did not considered when determining the thyristor switches firing angle. All previous publications only considered the starting current as the individual control signal for estimating the switches firing angle. In this study, the standalone MG frequency, the MG bus voltage, and the wind generator starting current have been employed to control both thyristors firing angle and wind turbine blade pitch angle simultaneously. Also, in the previous research, there is no coordination between the thyristor switches firing angle and the wind turbine blade pitch angle. The proposed hybrid electromechanical soft starting controller is provided with the coordination between the thyristor switches firing angle and the wind turbine blade pitch angle. The rest of the paper is organized as follows:

Section 2 describes the architecture of the investigated MG system. Section 3 presents a complete description for the proposed coordinated hybrid controller. Section 4 describes the main findings and results before and after employing the proposed controller. Also, the main advantages, and merits of the proposed controller are reported in Section 4. Conclusions are summarized in Section 5.

2. MG network architecture

Fig. 1 shows the architecture and layout of the investigated MG network. More details about the MG network, the micro sources modeling, the MG load representation, and the MG frequency and voltage control are available in [14–18]. The investigated MG consists of 4 buses network. Wind generation system (with rating 50 kW and 0.92 power factor lagging) locates at bus #2. 10 kW photovoltaic arrays are shunted to bus #3. Solid Oxide Fuel Cell (SOFC) (30 kW) is connected at bus #4. A flywheel (a storage device 30 kW, 0.5 kWh) is connected to bus #1. During normal operating condition, the MG is connected to the main grid and works on the normal connected mode. During fault or big disturbance occurrence in the main grid, the MG will be automatically disconnected from the main grid and acts on the standalone mode. The flywheel acts as a reference bus for the standalone MG. More details and descriptions about micro sources modeling and performance during the standalone mode are available in [19,20]. Controlling of the MG frequency and voltage during both the grid connected and the standalone modes are described in [21]. We used Matlab® Simulink® Software to develop the model in Fig. 2 for the MG.