Renewable and Sustainable Energy Reviews 47 (2015) 416–426

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Modelling and sensitivity analysis of isolated microgrids

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A R T I C L E I N F O

Article history:
Received 12 September 2014
Received in revised form
2 January 2015
Accepted 8 March 2015
Available online 30 March 2015

Keywords:
Microgrids
Small-signal stability
Distributed generation
Doubly fed induction generator

A B S T R A C T

In conventional generation systems, the possibility of system restoration and reducing power swings among different generation units is high, as an adequate reserve can be supplied from neighboring generation units to restore the operation. In contrast, the situation is different in the case of isolated microgrids, as the system reserve and capabilities of the whole system to recover from disturbances are limited, especially when the microgrid is supplied by intermittent sources as wind energy. This paper presents the state space modelling of isolated microgrids supplied by different energy sources, and thereafter, the eigenvalue sensitivity analyses are conducted. The main contribution of this paper is that a detailed model of an isolated microgrid supplied by different energy sources, particularly battery units and doubly-fed induction generators is presented. Moreover, in contrast to the most recent papers, which have discussed the state space modelling of several energy sources and have not studied the effect of load dynamics on the stability of power systems, this paper includes the dynamics of two of the most common loads, heating and induction machines. Their effects on the stability of the microgrid are discussed in detail.

Contents

1. Introduction

Traditionally, the question of power system stability has been connected to maintaining synchronism among energy sources. The production of electricity in the conventional utility is primarily

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http://dx.doi.org/10.1016/j.rser.2015.03.025
1364-0321/

Nomenclature

A, B, C, D	state variables, control, output, and feed-forward matrices, respectively
P_{max}	inverter maximum power
C	battery stored energy
Δt	time interval
${P_t}^{E_d}$, ${P_t}^{E_c}$	battery discharge/charge power
η_d, η_c	battery discharge/charge efficiency
m_p	inverter droop coefficient
κ	battery charging level
δ	coordinate angle of rotation
i_i, i_o	LCL filter input/output currents
v_o, v_g	LCL capacitor voltage and microgrid node voltage, respectively
ω	grid operating frequency
$\tilde{p}$, $\tilde{q}$	inverter instantaneous active and reactive power, respectively
ω_c	cut-off frequency
P, Q	active and reactive power, respectively
Δ	linearized variables operator
T_e, T_{sh}	wind turbine electrical and shaft torque, respectively
H_t, H_g	turbine and generator inertia constants, respectively
θ_{tw}	wind turbine shaft twist angle
ω_t, ω_r	wind turbine and generator angular speeds, respectively
ω_s, ω_{elb}	wind turbine synchronous and electrical base speeds, respectively
K_{sh}	wind turbine shaft stiffness
V_{dc}	dc-link voltage
z_P	thermostatic load state variable
α_t	transient load exponent
T_P	thermostatic load time constant
H	induction machine inertia constant
T_m, T_{e_m}	induction machine mechanical and electrical torque, respectively
s	induction machine slip
T_2	induction machine constant
d	subscript denoting the direct-axis component of a variable
q	subscript denoting the quadrature-axis component of a variable
$*$	superscript denoting a reference value
$\cdot$	superscript denoting differentiation with respect to time

secured using synchronous generators, and for that reason it is important to secure their synchronism and parallel operation. Therefore, the question of stability in conventional power systems is mainly based on the stability of synchronous machinery and on the relationship between the active power and rotor angle of the generator [1,2].

Nowadays, the justification for the large centralized station has weakened due to depleting conventional resources, increased transmission and distribution costs, deregulation trends and environmental concerns. Distributed generation sources (DGs) are commonly used for small scale generation and can offer a solution to many of the centralized generation challenges [3,4].

Microgrids are considered as clusters of distributed energy sources, loads and controls, organized to deliver the optimum energy service [5]. The most common perturbations in power networks can be analyzed by the small signal stability study. The small signal stability analyses have been investigated in several papers. In [6,7], both Lihui and Yang, respectively, presented stability analyses of microgrids supplied by the main utility along with the contribution from wind energy to detect the critical modes, which can influence the stability. In [8], Zhixin studied the inter-area oscillation problems caused by high penetration of grid-connected doubly fed induction generators (DFIGs), and a damping controller was designed to show the competency of that controller. Amir in [9] investigated the modelling and stability analysis of DFIGs interfaced to the grid via a series-compensated transmission line, and the critical parameters, which influence the system stability, were identified. A coordinated tuning of the controller to enhance the damping of the oscillatory modes, which can deteriorate the stability of DFIGs in grid-connected mode, was shown by Yateendra in [10]. The use of energy storage systems for a grid-connected doubly fed induction generator was shown in [11] by Mishra. The storage systems were employed to counter the intermittent nature of wind turbine power. A coordinated control scheme was used to enhance the damping of the oscillatory modes.

DGs are normally located near to customers and are interfaced to networks via electronic inverters to regulate the output. DGs interfaced via inverters are considered one of the most common energy sources supplying microgrids. In [12], Zhixin conducted a small signal stability analysis of an isolated microgrid, supplied by a synchronous generator operating as a slack bus and other DGs interfaced by electronic inverters to detect the critical modes. In [13], Bottrell focused on the control loop dynamics of the converters, which interface DGs to supply isolated microgrids. The converters models were linearized and the participation analysis of the critical eigenvalues was presented for the whole microgrid. The author showed that the critical eigenvalues are mainly associated with the voltage and droop controller state variables of the converters. In [14], Hassan provided stability analysis of microgrids supplied through inverters. Optimal design of inverter control loops was implemented and the control parameters were generated by particle swarm optimization.

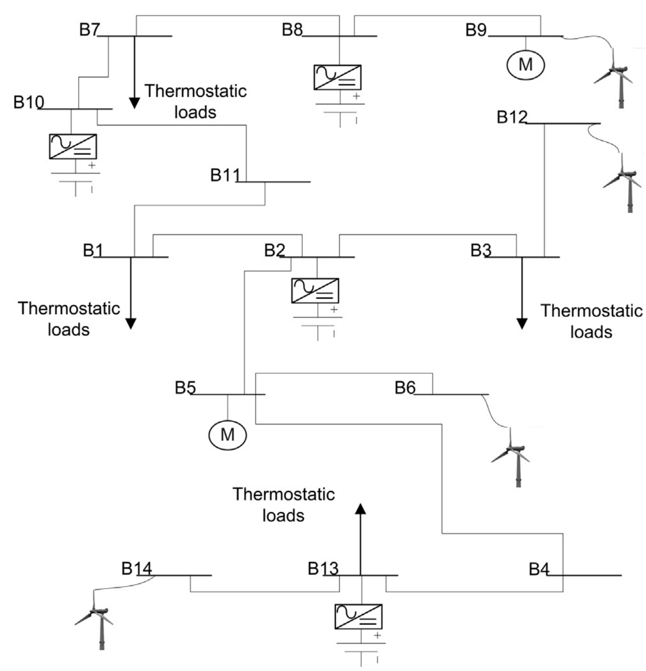

Fig. 1. Microgrid layout