Sustainable Energy Technologies and Assessments 13 (2016) 68–75

Contents lists available at ScienceDirect

Sustainable Energy Technologies and Assessments

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

Original Research Article

Islanding operation of hybrid microgrids with high integration of wind driven cage induction generators

Mir Nahidul Ambia, Ahmed Al-Durra *, Cedric Caruana, S.M. Muyeen

Electrical Engineering Department, The Petroleum Institute, P.O. Box 2533, Abu Dhabi, United Arab Emirates

A R T I C L E I N F O

Article history:
Received 20 November 2014
Revised 6 October 2015
Accepted 17 November 2015

Keywords:
Battery energy storage system
Frequency loop
Induction generator
Islanding
Micro-grid
Resynchronization

A B S T R A C T

This paper proposes two control strategies for the islanding operation of hybrid microgrid with a high penetration of wind driven cage induction generators. The control strategies combine approaches traditionally applied to self-excited cage induction generators with recent approaches for microgrid's islanding operation. The proposed control strategies aim to facilitate the higher integration of cage induction generators in microgrids. The first strategy is based on direct frequency and reactive power control while the second one uses an artificial grid to regulate the voltage amplitude and frequency. The proposed schemes are tested in PSCAD/EMTDC using a real wind speed pattern measured at Hokkaido Island of Japan. Simulation results show the successful operation of both schemes. The implementation simplicity and cost-effectiveness of both schemes are explained as well.

Introduction

Significant effort is being directed nowadays for increasing the share of alternative energy in the energy mix. The increase in the presence of distributed generation (DG) and the presence of multiple DGs in proximity to one another has brought about the concept of the microgrid [1,2]. Local DGs, loads and smaller scale energy storage systems can be interconnected to form a microgrid [3]. The physical proximity of the generation and the loads allow technical benefits and control flexibility that provides opportunities for increasing the efficiency, enhancing the reliability and improving the power quality of power systems [4]. Microgrids also have the potential to alleviate the present high levels of power flows in critical grid sections [5]. In such way, distributed energy resources, rather than burdening the system, add benefits to the power system [6]. The microgrid can operate in both grid connected and islanded modes of operation [7]. Islanded operation may be intentional or forced. Islanding operation capability allows the microgrids to continue supplying local loads even when the utility grid fails. This is in contrast to distributed generators operating on the utility grid that are required to disconnect once islanded operation is detected [8]. Sectionalizing switches can be used to isolate the microgrid for islanded operation [5]. The arrangement also allows intentional disconnection to reduce the dependency on the grid and possibly exploit more alternative energy.

The balance between the supply and demand is one of the most important requirements of microgrid management. Any imbalance in power can lead to significant frequency deviations due to the low inertia present in the system [3]. The frequency and also the voltage magnitude of islanded microgrids have to be controlled [3,5]. The inclusion of energy storage elements as part of the microgrid and the use of load shedding techniques are considered as effective solutions to allow high dynamic control and hence avoid large frequency and voltage excursions [3,9,10].

The different operational philosophy of microgrids as compared to traditional power networks brings about the need of adequate control strategies. Tiered control strategies are typically used. Primary, secondary and tertiary control algorithms are proposed in [6]. The primary control regulates the frequency and the voltage to ensure stable operation. This level of control is crucial and needs to be operated in a reliable way. The aim of the secondary control is to minimize the frequency and voltage deviations and drive the average deviation to zero. Tertiary control achieves the optimal distribution of the load between the energy sources for more economic operation. The secondary and the tertiary controls can be combined in the same algorithm [10,11]. Due to the distributed physical location of the elements of the microgrid, the control schemes for the different control tiers can be classified into two main groups as regards the use of control wire interconnections [9]. The first group requires critical interconnection lines between the elements. Apart from the cost, the dependence on the control lines limits the system reliability and expandability. The second

* Corresponding author.

http://dx.doi.org/10.1016/j.seta.2015.11.002
2213-1388/

Nomenclature

BESS	battery energy storage system
DG	distributed generation systems
L_{AC}	AC load consumption
L_{DC}	DC load consumption
P_{PV}	photovoltaic cell output power
P_W	wind turbine extracted power
P_{IG}	generator output power
V_W	wind speed
$C_P(\lambda, \beta)$	power co-efficient
λ	tip speed ratio
ρ	air density
R	radius of the turbine
R_{NAS}	battery internal resistance
ΔP_{sync}	adjusted set power from re-synchronization block
ΔP_f	adjusted set power from secondary frequency control block
P_{conv}	power transfer through interlinking converter between AC & DC buses
P_{conv}^*	reference power transfer through interlinking converter between AC & DC buses
V_{PoC2}, V	voltage measured at point PoC2 and PoC1
V_{PoC2}^*, V_{PoC1}^*	reference voltage at point PoC2 and PoC1
f	measured system frequency
f^*	reference for system frequency
L_1	medium length line
L_2	short length line
SS	sectionalizing switch
θ_{PLL}	PLL angle
I_{conv_d}, I_{conv_q}	d-axis and q-axis current
$I_{conv\_d}^*$, $I_{conv\_q}^*$	d-axis and q-axis reference current
$\Delta\omega_{sync}$	frequency reference
V_{LAC}	voltage at AC load
P_{WF}	output power of wind farm
P_{sm}	smoothen output power
ω_{IG}	rotational speed
P_{grid}	power export or imported by grid

group bases the control only on local measurements. This leads to a higher reliability and more flexibility in the location of the elements.

A number of distributed generators are interfaced to the grid through a power electronic inverter. Two forms of control can be used to operate the inverter – PQ control and VSI control [5,10,12]. In PQ control, the inverter is set to supply/absorb set active and reactive power references. Typically the PQ inverter is set to deliver all the active power available at its input and to provide a fixed reactive power, else participate in the voltage regulation [10]. Sources that require a maximum power tracker algorithm are interfaced through a PQ controlled inverter [12]. In VSI control, the inverter is controlled to supply the load with given values of voltage and frequency. The real and reactive power outputs will then be defined automatically [5].

Primary control can be achieved through a central controller that needs high bandwidth communication with the microgrid elements. Flexible solutions require that each inverter operates only on the basis of local measurements and hence independent of the actual configuration of the microgrid and the other generators [5]. Isochronous control can be used where the frequency is controlled to a constant value but this can be applied to only one unit [5]. Voltage and frequency droop control is a common solution as it automatically allows for power sharing between parallel units [5,10]. Droop control presents the advantages of low cost, simple expansion of the system, increased redundancy and simplified supervisory control [4]. Implementation of the droop control should consider the line impedance due to the different characteristics of high and low voltage lines [6]. The degraded frequency and voltage regulation due to the droop control is generally considered acceptable if the frequency and amplitude deviations remain within predefined limits [6,9]. In microgrid islanded operation, one or more inverters will be operated in VSI mode to provide a reference for the voltage amplitude and frequency hence allowing the other inverters in PQ mode to continue operating [10]. Despite the voltage and frequency regulation, the microgrid voltage will not be in phase with the utility grid voltage. To avoid hard transitions when reconnecting to the grid, the microgrid voltage can be synchronized to the grid voltage before reconnection [8].

If the droop controlled frequency stabilizes to a value different from the nominal one, storage devices would keep on injecting or absorbing active power [10]. In order to limit the required capacity of the energy storage elements, correcting permanent frequency deviations during islanded operations should be one of the key objectives of the control strategy [10]. This is precisely the aim of the secondary control, which will adjust the operating point of the sources accordingly. Secondary control can be performed locally or through a central controller. Central secondary control can be done on a low frequency basis to restrict the bandwidth requirements of the communication system [11]. The droop characteristic can be implemented is such way that it has the ability to shift the settings in response to deviations from the nominal frequency thus avoiding the need of the central controller [13].

Microgrids facilitate the integration of several kinds of renewable energy sources [5]. Wind energy is no exception. The growth rate of wind energy has increased significantly because of available wind resources and rapid technical development of wind farms [14,15]. Several control strategies have been published for the integration of wind turbines to the grid. Recently double fed induction generators (DFIG) and permanent magnet synchronous generators (PMSM) have become popular. They offer advantages of variable speed operation and control of the wind energy conversion. However a large number of cage induction generators are still used for wind energy conversion. The cage induction machine is attractive for wind energy generation due to its low cost, robustness, absence of moving contacts and ease of maintenance [16–20]. It is also widely used in industry. Various solutions for the self-excited induction generators have been published in the literature. Reactive power consumption and poor voltage regulation under varying speed can be seen as the major drawbacks of induction generators [17]. Advance in power electronic converters led to the development of low cost schemes for the regulation of the cage induction generator output voltage and frequency [20]. Most of the research paper with ac micro-grid system has rarely considered induction generators due to its reactive power consumption and poor voltage regulation. In [21] a back to back converter is used in the microgrid system with DC sources as major source. A real power controlled is designed for islanding operation in [22] for AC DC microgrid system.

This paper proposes two control strategies for the islanding operation of AC–DC hybrid microgrids with a high penetration of wind driven cage induction generators, where the previous research real and reactive power control [21,22] is modified. The first strategy is based on direct frequency and reactive power control while the second one uses an artificial grid to regulate