Electrical Power and Energy Systems 62 (2014) 175–182

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Microgrid dynamic response during the pre-planned and forced islanding processes involving DFIG and synchronous generators

Ricardo Leon Vasquez-Arnez [a,*], Dorel Soares Ramos [b], Tesoro Elena Del Carpio-Huayllas [b]

[a] Foundation for The Technological Development of The Engineering Sciences, Sao Paulo 05615-010, Brazil
[b] Electric Power and Automation Engineering Dept., University of São Paulo, Sao Paulo 05508-900, Brazil

ARTICLE INFO

Article history:
Received 30 September 2013
Received in revised form 11 April 2014
Accepted 16 April 2014
Available online 16 May 2014

Keywords:
DFIG generator
Forced islanding
Load shedding
Microgrid systems
Pre-planned islanding

ABSTRACT

In this article, some important issues associated to the dynamic response of a microgrid system are addressed. In particular, issues related to the pre-planned islanding mode of operation, load shedding, loss of one generator and the failure to shed an unforeseen connected load are studied. In this context, the dynamic behavior results of a Doubly-Fed Induction Generator (DFIG) and two other synchronous sources (a diesel and a small hydro-generator) within a microgrid, are presented. The overloading condition can occur due to causes ranging from poor load schedule, inadequate switching of circuits within the microgrid, illegal connection of load by some low voltage consumers, etc. In most of the simulated conditions the microgrid generators resumed their operation after clearing the disturbance. However, under some critical conditions, like in the case of a considerably large load connected, the microgrid was unable to return to the pre-fault condition and even failed while trying to gain stability for this new load condition. Because microgrid systems normally have low equivalent inertia, it was also observed that very little to practically no overload can be accepted by the generators.

Introduction

Microgrid systems, when properly designed, have the ability to separate and reconnect to the distribution utility. This ability gives microgrid systems the possibility to continue feeding their own islanded portion. In addition, provided an agreement exists with the distribution utility, microgrids can supply their surplus generation whenever they have excess capacity. This supply of surplus generation is particularly attractive for periods when the utility faces peak periods of demand. However, during certain operative conditions the microgrid could be subject to failure. It is the case of some transition conditions like those from the grid connected to the islanded mode of operation in which an excessive load (larger than the generators capacity) is connected to the microgrid [1].

The most common way to prevent the microgrid from undergoing a complete collapse is to shed the amount of excess load connected. By relieving the overloaded generator(s) it is very likely that the stability of the microgrid will be recovered. Among the pioneering references addressing the microgrid concept and its benefits for the power industry are [2–5]. The transition from the grid-connected to the islanded mode of operation following a fault and its respective stability behavior (without considering the connection of large unforeseen loads) was already addressed in some previous works [6,7]. Some issues related to the stability control in microgrids, specifically small signal and transient analyses as well as voltage stability, were discussed in Ref. [8]. However, such control approaches are mainly directed to inverter-based microgrids. Typically, the load shedding strategy is applied once the system frequency starts to drop from its nominal operative value (i.e., 50 Hz or 60 Hz), and this concept was also extended to the case of microgrid systems. Apart from this traditional method, some other approaches, although not practically proven, were also proposed for the case of microgrids.

The load shedding issue, load restoration as well as some schemes for the protection of generation units during abnormal frequency conditions are presented in Refs. [9,10]. A strategy to shed an optimal number of loads in an islanded distribution system, based on the rate of change of frequency (RoCoF) and the customers' willingness to pay during periods of outage, is presented in Ref. [11].

Recently, methods such as the use of intelligent load management in industrial and microgrid facilities were proposed [12,13]. In particular, [13] proposed an algorithm that systematically removes loads from the microgrid until the power balance between load and generation is reached. However, given the small inertia of the generators to support stability issues as well as the

* Corresponding author. Tel./fax: +55 11 2528 3666.
E-mail address: rarnez@fdte.org.br (R.L. Vasquez-Arnez).

http://dx.doi.org/10.1016/j.ijepes.2014.04.044
0142-0615/

Table 1
Load shed as a function of the frequency drop.

Step	f (Hz)	(%) Of load
1	59.3	10
2	58.9	15
3	58.5	As required to avoid going below 58.2 Hz

Table 2
Load shed as a function of the RoCoF method.

f (Hz)	RoCoF df/dt (Hz/s)	Total load (%)
59.3	0.4	10
59.3	1.0	25
59.3	2.0	35

inherent delay time of the circuit-breakers to open such loads in a systematic way is probably not feasible using the proposed approach.

Additionally, the above references do not discuss the difficulties that microgrid generators face while dealing with critical conditions, such as the islanding process and the connection of unexpected extra loads. Thus, the results presented herein aim to contribute to the development of the microgrid technology by addressing such operative conditions. In addition, this article intends to answer some of the questions set by the department of energy [14] related to overload and under-frequency issues in micrograms.

According to [15,16], the two widely used load shedding methods are the following:

(i) Traditional frequency drop with load percentage shed. Typically, the load shedding scheme can be performed in three (and up to six) steps [15]. Table 1 presents an example of the percentages of load shed for a three-step scheme.
(ii) Use of the rate of change of frequency (RoCoF) and load percentage shed (Table 2). This method evaluates the speed at which the frequency (df/dt) is declining. This evaluation enables the characterization of the type of contingency occurring in the system at various instances, thereby, enabling the system to provide the most adequate load shedding scheme [16]. For example, regarding the frequency drop of 59.3 Hz (shown in Table 1), the df/dt could be set at the values presented in Table 2.

The above under-frequency control methods are commonly used by many distribution utilities. In the context of this paper, the entire load exceeding the normal power demand of the microgrid internal generation will be shed. This load shedding is performed regarding the simulation response of the generators for returning to the pre-overload condition. Note also the inherent differences that exist between the main grid and a microgrid, as in the former case (main grid), for example, the inertia of the generation sources is far greater compared to the generators within the microgrid. Generally, small gen-sets have no overloading capability. Small wind and hydro generators may admit, although it is not recommended, very little temporary overload (up to 10% [17]) to avoid overheating. Still, a brief comment on what would be the percentage of load to be shed, if the above methods were also used, will be included whenever appropriate.

Description of the microgrid used

During the transition from the grid-connected to the islanded mode of operation, the power control of the microgrid generators must act quickly. This is because they must start controlling the frequency of the islanded section. Whenever power in the network is lost, the microgrid generators should be able to pick up and feed the load of the islanded system after the switch at the Point of Common Coupling (PCC) has opened.

The microgrid system used in the simulations is connected to the utility through a main circuit-breaker (CB) in series with a 6 MVA, 13.8/2.4 kV transformer (Fig. 1). The energy sources considered here are a synchronous generator driven by a diesel engine (connected to the PCC through CB-1); a wind turbine driving a Doubly-Fed Induction Generator (DFIG) connected to PCC through CB-3; and another small synchronous hydro-generator (SHG) connected to PCC through CB-2. No PV arrays (solar panels) or sources requiring energy storage elements were considered because the primary focus of this research is to analyze the dynamic behavior of the system. Additionally, the machine equations are omitted here because they can be found in the available literature regarding electric machines. The DFIG wind generator is connected to the microgrid through a 2.4/0.69 kV transformer.

The normal loads (*Load 1*, *Load 2* and *Load 3*) were specified as constant power loads. The extra loads used in the overloading condition (*Load 1A*, *Load 2A* and *Load 3A*) are represented by equivalent motors (Fig. 1). These extra loads are connected to their respective generator through CB-4, CB-5 and CB-6. The complete system was implemented in the EMTDC/PSCAD® program [18].

Some components, such as the source models, the constant power loads and the asynchronous motors (dynamic loads), were taken from the software library.

Among the control systems independently built and defined are a basic speed regulator, a constant mechanical power regulator and a voltage regulator. Reasonably robust voltage and speed regulators are useful to help the machine cope with transient over-voltages and dips. The main parameters of the generators, such as the direct and quadrature reactances as well as the transient and subtransient time constants (X_q, T''_{do}, X''_q, T''_{qo}, etc.), were estimated according to Ref. [19].

Immediately after the simulation of the initialization transient has reached a stable condition, all three generator models are switched from being ideal sources to non-ideal machines, which means that the dynamic model of each machine (including their respective regulators) is enabled.

Diesel generator model

The main control functions implemented on the diesel generator are shown in Fig. 2(a). These control functions are a voltage regulator, a speed regulator and a constant mechanical power regulator.

Basically, the voltage regulator is linked to the machine through the field voltage and current (E_f, I_f). In Fig. 2(b), the rms voltage (V_{rms1}) is measured at the terminals of the machine and compared with the reference voltage (V_{ref}). The difference between these two values is multiplied by a gain and improved, if an undesirable frequency response was obtained, through a lead-lag compensator. To prevent the generation of either too high or too low values (e.g., negative values), a voltage limiter is typically used. The resulting signal is then added to the initial field voltage specified (E_{f0}), from which E_{f1} is obtained. The latter value (i.e., E_{f1}) is then affected by a real pole function (to attenuate high frequency components, chattering, etc.) to finally obtain the filtered field voltage of the controller (E_{f_ftd}) that will produce the controlled voltage in the regulator and correct the synchronous generator terminal voltage.

The speed regulator acts upon the generator speed (w), which has a direct relationship with the machine frequency. An additional component of the speed regulator is the mechanical torque (T_m) showed in Fig. 2(a). The task of the mechanical power regulator