Electric Power Systems Research xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Electric Power Systems Research

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

Adaptive load shedding scheme for frequency stability enhancement in microgrids

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ARTICLE INFO

Article history:
Received 2 December 2015
Received in revised form 15 June 2016
Accepted 17 June 2016
Available online xxx

Keywords:
Adaptive load shedding
Inertia constant
Frequency control
Microgrid
Power system reliability
Under-frequency load shedding

ABSTRACT

The imbalance between the generated power and the load demand is the major factor that is usually responsible for frequency instability in power systems, most especially islanded microgrids. To determine the size of the loads that should be shed and their appropriate locations in the power system, to maintain the system frequency within the permissible limits, this paper presents an effective adaptive control scheme. In the proposed controller, a stepwise load-shedding approach is designed in the islanded MGs to regulate the grid frequency while providing the amount of power shortage. To this achieve, it locally measures the system parameters most especially voltage and frequency signals. Thereafter, a stepwise load-shedding will take place in locations where the highest voltage drop and frequency variation are experienced. The load-shedding step changes according to certain factors such as shedding speed, location and value, and the rate of frequency change. The proposed approach eliminates the adjustable loads to return the frequency back to the desired value. Simulation results of the proposed method under different practical scenarios, when compared with the conventional PID controller, provide considerable enhancement in the power system frequency stability.

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1. Introduction

The imbalance between the amount of generation and the load demand is the major factor that usually results in frequency instability in power systems. If not urgently and properly managed, this action could cause an unwanted blackout in the power system, especially a microgrid (MG) operating in islanded mode [1–8]. During normal load variations in a grid connected microgrid, frequency is regulated by the automatic generation control (AGC) system [9–12]. However, in case of a sudden power deficit, perhaps due to disconnection of the MG from the main grid or a substantial decrease in the generated power at islanded mode, the AGC would no longer be able to stop the rapid frequency fall even in the presence of enough spinning reserve [6].

Therefore, to retain the power balance and prevent frequency from further falling below the specified value, adequate loads should be shed as prompt as possible. In other words, load shedding under a severe imbalance between the generation and load demand has been generally adopted in the power industry as an effective way to maintain frequency stability of a power system.

A microgrid could operate in two modes: gird-connected mode and off-grid or islanded mode [13–17]. In the isolated mode, if the load demand is less than the amount of power generated, the power generated by the distributed energy generation sources decreases as it maintains power equilibrium and/or used by the energy storage (ES) systems for storing generated excess power and using this power when needed. If the load demand is more than the amount of power generated, ES system is discharged and in addition, a mechanism to eliminate some loads may be necessary [18].

Different load elimination methods have been presented widely for controlling and monitoring of frequency and voltage in power systems. For example, protective algorithms have been designed to eliminate loads in these systems to forestall different forms of instability in the power systems [16,19]. Furthermore, total equivalent inertia constant exists for the isolated MGs which by using the rotor fluctuation equation and the dependence of equivalent inertia constant on it, the amount of active power shortage in the grid is estimated [20]. Through this, the rate of change of frequency

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http://dx.doi.org/10.1016/j.epsr.2016.06.037
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Nomenclature

Acronyms

AGC	automatic generation control
DER	distributed energy resources
ES	energy storage
I	integrated controller
MT	micro-turbine
PD	proportional derivative
PV	photovoltaic
PID	proportional–integral-derivative
ROCOF	rate of change of frequency
UFLS	under frequency load shedding
WT	wind turbine

Variables

H_i	the inertia constant (s)
f_i	frequency (Hz)
f_n	nominal frequency (Hz)
P_{mi}, P_{Ei}	mechanical/electrical power of the *i*th turbine (p.u.)
ΔP_i	the active power shortage of the *i*th unit (p.u.)
ΔP_k^{set}	the *k*th active power shortage created in the isolated grid (kW)
H_k	the inertia constant equivalent to the *k*th power shortage (s)
H	the inertia constant equivalence of the total MG

(ROCOF) is calculated in the grid under study. In this method, the multi-stage typical under-frequency load elimination strategy is implementable [21].

By quickly estimating the power reduction, we can return frequency stability to isolated MGs. The weak point of the common approaches is that they do not consider the combination of different scenarios [22]. During the occurrence of such incidents, a group of load elimination relays follow the under-voltage relays and each one acts independently. In this way, the system operator will observe the non-optimum load elimination performance and incoordination in the system [23]. All together, the weak points of typical protective plans during the occurrence of major interruptions which lead to system blackouts, are many.

Usually a combination of incidents such as loss of generators and transformers as well as disconnection of some transmission lines can occur in a power system. During such incidents the system experiences a severe frequency loss and decrease in the voltage stability margin simultaneously. In fact, after the occurrence of interruptions such as sudden loss of a generating unit, the location of voltage disintegration and the amount of active power demand depends on the interruption location. However, in the conventional and smart load elimination plans, the places of load shedding are independent of the interruption locations. Load shedding at the weak points in this system, raises the stability margin of the system voltage which results in increase in the system protection under combinatorial interruptions [5,24–26].

To achieve this, load shedding relays are set in such a way that whenever there is a reduction in the reduced frequency below the acceptable level, certain amount of load can be shed to maintain grid frequency stability. On the other hand, in large disturbances of power system, usually frequency decays are accompanied with voltage decays. Voltage decays at load buses reduce the system loading, so frequency decline is decelerated and actual levels of load shed by under frequency load shedding (UFLS) are reduced relative to the levels required and expected [1,27,28]. In most practical conditions, the load shedding level may be more or less than is needed to maintain frequency in acceptable level that may lead to high costs for grid and their connected loads. To avoid such problems, this paper presents a load shedding adaptive control approach using system frequency and voltage signals.

It is very intricate to determine the amount of load shedding required to improve frequency stability in MGs considering sudden change in renewable resources, due to connection to and/or disconnection from the grid. Additionally, the power generation units are distributed over the MG and the structure of these sources changes with time. In other words, the equivalent inertia constant of the grid is not fixed with time and the power deficit estimated using a predefined inertia constant may be misleading. In addition, active power deficit is usually accompanied by a reactive power deficit. This reactive power deficit results in a sudden decrease in the voltage of all the buses which in turn reduces the loads power that decreases the frequency derivative. Moreover, when an amount of the load is shed, reactive power deficit decreases the voltage and consequently the power consumed by loads. Hence, the change in the frequency derivative will be less than the expected value.

The research work presented in this paper is a continuation of the previous work of the authors [5,13,24–26,29]. As mentioned before, this paper uses a new multi-stage adaptive load shedding approach that estimates equivalent inertia constant in MGs based on the composition of their resource changes with time. Thereafter, it will estimate frequency changes more accurately in MGs. Meanwhile, it is necessary to determine the impact of voltage-dependent loads on the estimated power deficit. To achieve this, two filters are used to calculate the voltage indicator. The first filter output signal specifies the voltage drop before occurrence of the disturbance and the output of the filter puts at disposal the value of the voltage loss for a few seconds after the disturbance. By integrating the instantaneous value of voltage drop using the second filter, the index of the desired voltage is obtained in determining the bus voltage profile. Combining the frequency and voltage signals, a load shedding trip signal is issued.

Initially, this paper presents a conventional mechanism for determining the equilibrium point or power shortage by calculating the inertia constant of the generator of an isolated MG. Thereafter, the proposed adaptive control load shedding algorithm is presented. It is a smart method of selecting the effective bus in creating voltage and frequency stability concurrently. It also has the benefit of reducing the power imbalance in the grid under study. Finally, to evaluate the performance in terms of speed and accuracy of the proposed adaptive control strategy, different scenarios on the system are considered. The results obtained are compared with those obtained from a typical PID controller.

The main contributions of this paper are summarized below:

- √ The capability of the proposed approach to regulate the supply frequency within the permissible values by load-shedding the adjustable loads thereby ensuring uninterruptible power supply to the most critical loads;
- √ The proposed approach can effectively ensure frequency stability of both islanded and grid-connected MGs under different types of disturbances in the grid;
- √ The proposed UFLS scheme is not only independent of the MG parameters, but also considers power generation variations during the load shedding process.

2. The case study microgrid structure

The MG under study is a hybrid system of different distributed energy resources (DER). The DER considered are wind turbine (WT), Microturbine (MT), photovoltaic (PV), energy storage (ES) system and linear loads. The linear loads include first stage loads of 20 kW, second stage loads of 38 kW and third stage loads of 50 kW. These

Please cite this article in press as: M. Marzband, et al., Adaptive load shedding scheme for frequency stability enhancement in microgrids, Electr. Power Syst. Res. (2016), http://dx.doi.org/10.1016/j.epsr.2016.06.037

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