A MODIFIED ISLANDING DETECTION METHOD FOR HYBRID AC/DC MICROGRIDS WITH REDUCED DETECTION TIME

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ABSTRACT

Islanding detection is a mandatory feature for grid-connected multi-inverter Microgrids and must be done within 2 seconds after. However, the effectiveness of islanding detection methods (IDMs) is usually demonstrated by means of non-detection zones (NDZ). Among them, The Sandia frequency-shift (SFS) is considered as one of the effective islanding detection methods that possess small NDZs. Furthermore, considering the hybrid AC/DC microgrids with both AC and DC subgrids which are connected through an interlinking converter, because of different types of parameters and characteristics of the mentioned subgrids, conflictions or mal-operation may occur in islanding detection. Consequently, in this paper a new hybrid islanding detection method, using SFS and Rate of Change of Frequency (ROCOF) relay, to eliminate NDZs has been proposed for islanding detection in hybrid AC/DC microgrid. Furthermore, the islanding detection method of the interlinking converter has been modified and coordinated with converters of DC subgrid to improve its operation. Thus, the proposed method effectively combines the principles of active and passive methods that the islanding can be detected faster than conventional methods. This method is tested under various operation conditions using PSCAD/EMTDC. Simulation results show that the proposed method correctly detects the islanding operation and does not mal-operate in the other disturbances such as short circuit, load variations, capacitor switching in hybrid AC/DC microgrids.

INTRODUCTION

Islanding is an undesired situation in active modern distribution system with DGs because it could impair the safety of maintenance service workers and/or damage loads [1]. Therefore, a quick and accurate Islanding Detection Method (IDM) is essential for active distribution systems to avoid intentional islanding or upgrade the control system of DGs to operate islanded during grid outage. The main concept of most of the IDM techniques remains the same that some of the system parameters (voltage, frequency, etc.) change considerably with islanding but not much when the distribution system is grid connected [2]. Islanding detection techniques can broadly be divided into remote and local techniques. Local methods can be categorized into passive, active and hybrid methods [2].

In passive techniques, system parameters such as voltage, frequency, harmonic distortion, etc, are continuously monitored and compared with a predetermined threshold. Based on the system characteristics, one or more of these parameters may vary considerably when the microgrid is islanded. The difficulty of islanding detection when the load and generation in the islanded system closely match is the main problem of the passive techniques.

Active methods are based on the perturbation and observation concept. These methods inject intentionally deliberate disturbances in the DG circuit (via its electronic control scheme) to detect islanding. Although, Active methods provide a cheaper approach for islanding detection and can reduce the NDZ, the problems with these techniques are that they introduce perturbations in the system and detection time is slow as a result of extra time needed to analyze the system response of the perturbations [3].

Considering the advantages and the problems of active and passive methods, a suitable integration of these methods can be used to improve the islanding detection procedure and reducing the problems of these methods such as NDZs and long detection time. Consequently, Hybrid methods which are a combination of passive and active methods can be proposed.

It should be mentioned that so many types of active [2-3], passive [4-6] and hybrid [7] IDMs has been proposed for single inverter or multi inverter microgrids, however, these methods are not considered to be applied in a AC/DC microgrid in literature.

Considering the hybrid AC/DC microgrids, because of different types of parameters and characteristics of the mentioned subgrids, conflictions or mal-operation may occur in islanding detection. Consequently, This paper presents an integration of Sandia frequency-shift (SFS) (active method) and Rate of Change of Frequency (ROCOF) relay (passive method), as a hybrid islanding detection technique to overcome the short comings of both active and passive techniques in hybrid AC/DC microgrids.

PROPOSED MODIFIED ISLANDING DETECTION METHOD FOR HYBRID AC/DC MICROGRID

Among Various frequency islanding detection methods, Sandia frequency shift (SFS) is one of the most effective methods in islanding detection for active distribution networks [6-8]. Furthermore,, among passive IDMs, the Rate of Change of Frequency (ROCOF) relay is one of usual and general methods [8]. Consequently, in order to present the modified hybrid IDM method that integrates SFS method with ROCOF relay, a brief description and most important requirements of these methods are presented as follows:

Sandia Frequency Shift (SFS) IDM

This method tries to amplify small changes in frequency. Consequently, for islanded mode, the process produce a phase error in which continues until the frequency exceeds the threshold [6]. This method tries to amplify small changes in frequency. Consequently, for islanded mode, the process produce a phase error in which continues until the frequency exceeds the threshold [6].

For the SFS islanding detection method, the inverter phase angle (ϕ_{inv}) can be expressed as a function of the island frequency f_{is}, frequency of the grid prior to islanding, f_g, and the SFS parameters cf_0 and k [7]:

$$\phi_{inv} = \pi(cf_0 + k(f_{is} - f_g))/2 \qquad (1)$$

The load phase angle (ϕ_{load}) is a function of island frequency, the load resonant frequency f_0 and the load quality factor Q_f [7]

$$\phi_{load} = -\tan^{-1}[Q_f(f_0/f - f/f_0)] \qquad (2)$$

Considering, SFS method, the phase criterion can be extracted by equating the two phase angles in equations (1) and (2):

$$f_0^2 + f\tan[\pi(cf_0 + k(f - f_g))/2]f_0/Q_f - f^2 = 0 \qquad (3)$$

From (3), it can be demonstrated that the NDZ depends on the SFS parameters (cf_0 and k) and load parameters (f_0 and Q_f) [6]. To eliminate the NDZ, it is necessary to ensure that for all possible loading scenarios, the load and DG phase-angle inter-section point is an unstable operating point. This condition can be expressed as [6]:

$$\frac{d\varphi_{load}}{df_{is}} < \frac{d\varphi_{inv}}{df_{is}} \qquad (4)$$

Considering, equations (3) and (4), the value of ' k ' parameter can be selected to ensure that the frequency will drift away from the equilibrium point defined by the phase criterion. Differentiating the two expressions for the phase angle in (1) and (2) with assuming $f = f_0$ the value of ' k ' parameter can be expressed as [7]:

$$k > \frac{4Q_f}{\pi f_0} \qquad (5)$$

Rate of Change of Frequency (ROCOF) Relay IDM

ROCOF relay which is categorized in passive IDM monitors the voltage waveform and trips the breakers when the measured frequency change rate exceeds a preset value for longer than a pre-set time period. The ROCOF relay settings are chosen such that the relay don't operates for fluctuations governed by utility time constants [25]. ROCOF relay utilizes the generator swing equation to define ROCOF as follows [8-9]:

$$\frac{\Delta f}{\Delta t} = \frac{\Delta P}{2HG} f \qquad (6)$$

Where ΔP is the change in output power, f the system frequency, H the inertia constant of DG system and G is the rated capacity of DG system.

The block diagram which has been used to design the ROCOF relay is illustrated in fig. 1.

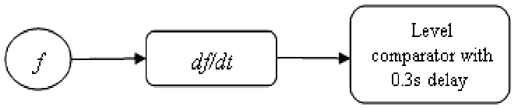

Fig. 1. Block diagram of ROCOF relay design.

The proposed hybrid IDM method integrates SFS method with ROCOF relay. Consequently, frequency drift will occurs immediately after islanding. With frequency drift, ROCOF relay detects the change of frequency. Thus, if the rate of change of frequency exceeds the threshold more than 300ms, the ROCOF relay will change the control system mode from grid-connected to islanding and then the voltage and frequency control of DGs are activated.

It should be mentioned that, using proposed method for islanding detection, the frequency doesn't need to exceed the threshold. So, islanding can be detected using the rate of change of frequency, even for zero power mismatches, before the frequency exceed limitations of system.

Furthermore, because of using the rate of change of frequency instead of frequency drift for islanding detection in this proposed method, there will be no more need to select large values for SFS parameters. However, the parameters should be selected as a way that islanding situation can be distinguished from other normal events in grid-connected mode. For example, parameter "k", which is the positive feedback gain of SFS control block, may cause in instability of DG units, especially for small microgrids if its value is increased in order to detect the islanding faster. While, using the proposed method, the islanding detection will be accelerated without need to

increase the "k".
For this method, the threshold value of SFS method will be selected as the base of normal events and the threshold value of ROCOF relay will be set considering the selected base.
A threshold setting of 0.3Hz/sec has been found to be the optimum value, with 0.3s – 0.7s operating time for the proposed method considering the mentioned rules.
The main flowchart of proposed IDM which has been applied in interlinking converter is illustrated in fig. 2.

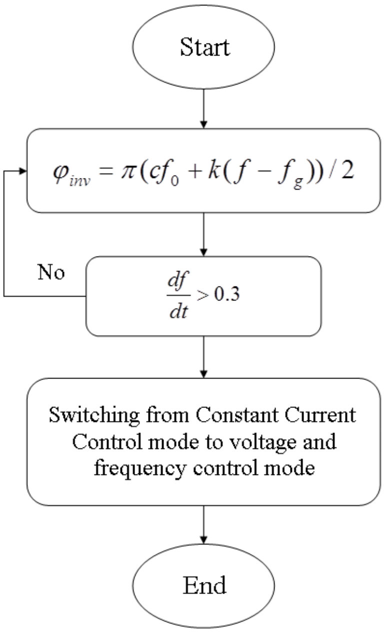

Fig. 2. Flowchart of the proposed methodology.

The Studied Hybrid AC/DC Microgrid with Interlinking Converter

Throughout the last decade, a number of studies have proposed the DC-AC hybrid MG system structure and control strategies to save energy, thereby reducing cost and increasing reliability. Discrimination of the DC power collection and consumption feeder from the conventional AC power distribution line provides several benefits. Firstly, each DC distributed generator does not have to install AC integration equipment to cope with AC integration problems, such as AC conversion and line synchronization. Secondly, DC loads can be directly fed from DC sources without any power quality disorders which may affect the main AC distribution system. Thus, it reduces power electronic equipment and maintenance costs for individuals, and promotes joining small scale domestic or even large scale urban systems to microgrid utilization [11-12].
Considering the futures of hybrid AC/DC microgrids, the main test system in which the proposed hybrid methodology is tested, has been proposed in Fig. 3. The studied hybrid AC/DC microgrid consists of two AC and DC subgrids which are connected through an interlinking bidirectional converter. Each subgrid contains two DGs operating in parallel at both grid-connected and islanded modes. The voltage source converter (VSC) is used as an interlinking converter in order to connect AC and DC subgrids. furthermore, the control system of the DGs manage the output power of DGs. Considering the grid-connected and islanding modes, two control strategies should be applied in control system of all VSCs.

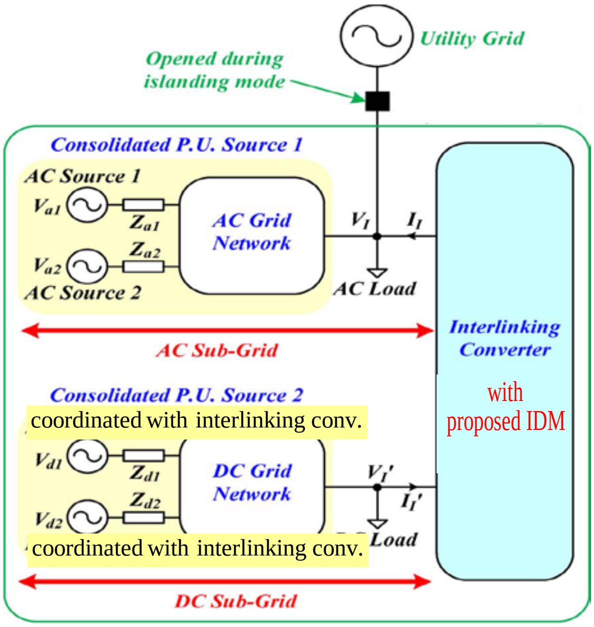

Fig. 3. Hybrid AC//DC system with proposed IDM

In grid connected mode, the two DG systems of both AC and DC micrgrids adopt Constant Current Controller to provide local power and the interlinking converter manages the power transfer between subgrids. This configuration uses dq space frame and reduces the burden of generation and delivery of power directly from the utility grid and enhances the immunity of critical loads to system disturbances in the utility grid [10].
In islanded mode, one of DG units must be used as a reference source to control the voltage and frequency of microgrid. For this test system, DG1 has been chosen for this purpose. Consequently, right after islanding detection, the control strategy of DG1 inverter must be switched from Constant Current Control mode to voltage and frequency control mode. Furthermore, this control strategy should supply reactive power of loads using DG1.
The proposed control of microgrid for this microgrid is Reverse Droop control. This control system uses two P-f Droop and Q-V Droop schemes as the following equations [10]:

$$f = f_n - \frac{P_n - P}{m} \quad (7)$$

$$V = V_0 - \frac{Q}{n} \quad (8)$$

The applied voltage and frequency control using Droop control concept is shown in fig. 4.

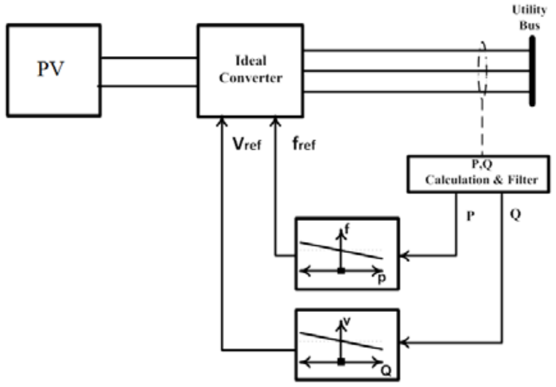

Fig. 4. Block diagram of voltage and frequency control using Droop control.

SIMULATION RESULTS

To verify the effectiveness of the proposed hybrid IDM, a hybrid AC/DC microgrid consisting of two DGs operating in parallel at both subgrids are implemented on PSCAD/EMTDC as shown in figure 3. During islanded mode of multi inverter AC/DC microgrid, the AC subgrid system control method is called master-slave operation, which means that one of DGs acts as the master and the others as affiliates. While, in grid-connected mode all DGs adopt Constant Current Control. Consequently, in islanded mode the master DG (1) turns to Droop control to provide voltage and frequency reference to the other DGs and interlinking converter.

For simulated scenario, the islanding event occurs at t=1sec and the electrical parameters of system and loads are shown in Table I.

Table I.
The electrical parameters of simulated system

	Parameters
Voltage	220V AC , 400V DC
frequency	60 Hz
AC DG_1	PI: k_i=100, k_p=0.2
	$1/n=15*10^{-4}$, $1/m=7*10^{-5}$
AC DG_2	PI: k_i=100, k_p=0.2
Interlinking converter	PI: k_i=110, k_p=0.25
AC Load	R=2.204, X=0.1
DC Load	R=2.304, X=0

In this scenario the AC/DC microgrid has been simulated considering zero power mismatch between DGs generation and loads consumption which can be supposed as the worst condition for islanding detection. As shown in Figs 5 and 6, the frequency and voltage of AC subgrid are almost constant during islanded mode with zero power mismatch.

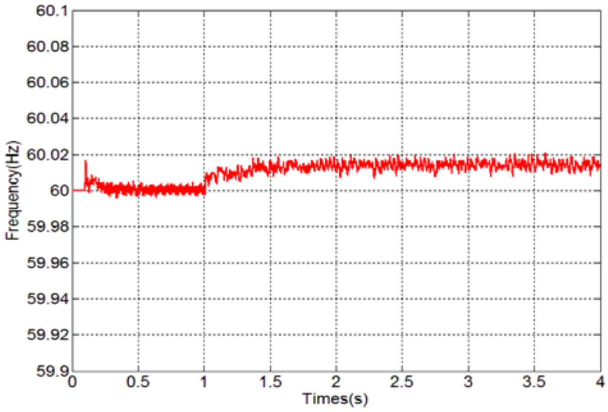

Fig. 5. Frequency of microgrid with zero power mismatch of system without using active IDM.

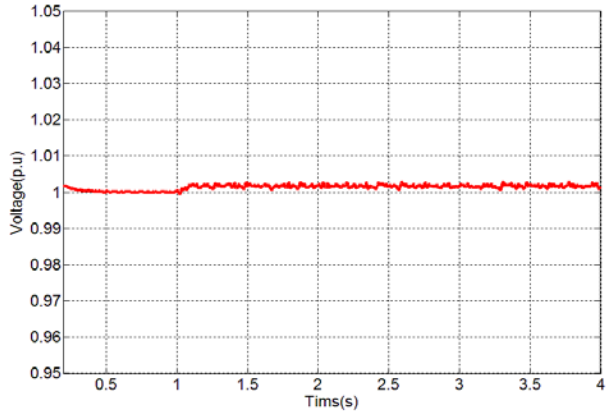

Fig. 6. Voltage of microgrid with zero power mismatch of system without using active IDM.

It should be mentioned that in this scenario, if just a ROCOF relay method used without any active IDM, the islanding couldn't be recognized.

Thus, using the proposed hybrid IDM, the microgrid islanding has been detected even for zero power mismatch with no NDZ. Then, the microgrid islanding has been recognized within 0.3sec and the ROCOF relay will operate. Consequently, the control system of DG1 can completely replace Constant Current mode with Droop control. finally, the Droop control compares the voltage and frequency of islanded microgrid with nominal values and tries to minimize their differences by generating required active and reactive power of DG units.

This process has been completed at *t=1.7sec*, using the proposed hybrid IDM, as shown in fig. 7. While, this time for conventional SFS IDM is at *t=2.7sec* which demonstrates *1sec* delay compared with proposed hybrid method. Furthermore, the frequency of microgrid varies so slightly in proposed method compared with conventional SFS method

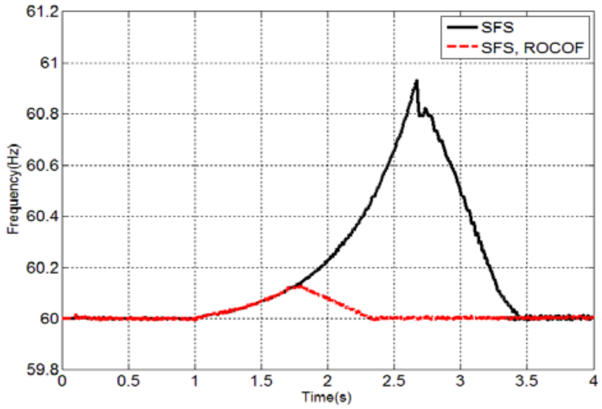

Fig. 7. Frequency of microgrid with zero power mismatch of system.

CONCLUSION

In this paper, A hybrid IDM has been proposed to detect islanding of an AC/DC microgrid system with multiple DG units operating at both grid-connected and islanded modes. It integrates the SFS (active method) and ROCOF relay (passive method), to overcome the short comings of both active and passive techniques.

Coordinated setting of ROCOF relay and SFS parameters which specialize the ROCOF relay operation just for SFS generated disturbances, decrease the values of positive gains and help the IDM system not to mal-operate in the other disturbances such as short circuit, load variations, capacitor switching. Furthermore, using proposed hybrid method, the islanded mode has been detected faster than using conventional SFS method. Thus, the variation of frequency and voltage domain with the duration of transients has been decreases, which could improve the stability of microgrid especially in islanded mode.

The proposed method is very simple and Simulation results, considering a hybrid AC/DC microgrid, highlight the effectiveness of the proposed approach especially the advantages of the proposed method: NDZ elimination and faster islanding detection compared with conventional method.

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