Analysis and Performance of Active Islanding Method for Grid-Tied High Penetrated Photovoltaic Systems

M. Vinay Kumar[1], U. Salma[2]

[1]Department of Electrical and Electronics Engineering, GMR Institute of Technology, Rajam, India

[2]Department of Electrical and Electronics Engineering, GIT, GITAM University, Visakapatnam, India

Abstract: ***The contribution of grid connected distributed generators (DGs) are growing year by year, as the demand for electrical energy is increasing at a steep hike due to rapid industrialization and fast growth in population.When thegrid doesn't function properly, it leads to damage of the electrical equipmentsand causes risk to operating personal. Hence, the forecasting of islanding is an important preventive measure for DGs to manage the safety requirements. Anti-islanding is an essential protectingfunction for DGsas per the standards and grid-code limits.Islanding detection methods should assure the disconnection of DGs during grid faults and unintentional islanding conditions.Anti-islanding methods are broadly classified into passive and active islanding methods. Usually, the active islanding methods intentionally change some of the electrical parameters, which can be detected when grid stops injecting current to the load, hence protects the system from forming an island.So, it's important to detect islanding condition quickly and also maintain the quality of the power. Photovoltaic (PV) systems are used as DGs due to its numerous advantages. This paper presents the design of grid-tied high penetrated PV systems usingan active frequency drift with a positive feedback anti-islandingmethod (AFDPF).Simulation is consequently done in the Matlab/Simulink environment to validate this proposed criterion. Results of simulation present its effectiveness, to confirm the authentication of the discussed method, the simulation results are deliberated.***

Keywords: Photovoltaic (PV) System, Grid-TiedPV Systems, Distributed Generation (DG), Anti-Islanding, Islanding Detection Methods (IDM), Non-Detection Zone (NDZ), Active Frequency Drift with Positive Feedback (AFDPF), Matlab, SIMULINK

1. Introduction

With increase in the demand for electrical energy due to rapid growth in population and industrialization, the need of the hour is to bridge the gap between demand and the supply. The centralized power generation technique is moving towards decentralized generation with the inclusion of distributed generators (DGs) to bridge the gap and also with respect to cost consideration and environmentalissues (1-6).

The sky rocketing prices of fossil fuels and the concerns about the green-house effect lead to search for alternative sources of electrical energy, ie., renewable energy sources (RES). The use RES of such as solar, wind, hydro, biomass are the promising ones. Among all the RES, PV systems using solar energy is gaining much attention due to its numerous advantages such as in-exhaustible energy source which is available throughout the world, decrease in cost of PV panels, increase in efficiency of PV cells, eco-friendly, little maintenance as the system is completely stationary, panels can be recycled etc., but the main drawback is intermittent availability of sunlight and non-uniform irradiation on solar panels due to occlusion effect. PV systems as DGs can be used in standalone mode for supplying power in hilly areas where erection of transmission lines is costly or can be used as grid connected mode for supplying power to the grid (7-9).

The block diagram of high penetrated grid-tied PV systems is shown in Fig.1 below.

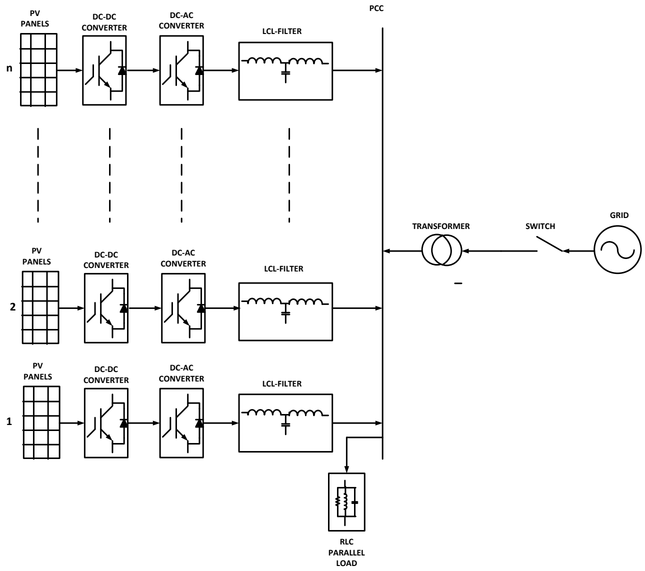


Figure 1: Block diagram of high penetrated grid tied PV system

With the inclusion of DG's into the power system, new difficulties and challenges arrivesand have to be addressed [10,11]. Islanding is one such challenge which occurs when a partof utility system containing both load and a DG gets disconnected from the grid and operates independently, in spite of grid stopping injecting the power to load, a local uncontrollable distribution network is formed. Though islanding happens very rarely, but its occurrence leads to severe damage i.e., loss of life of operational staff, damage to consumer equipmentand later during reconnection to the grid, if not synchronized properly,it may lead to damage of DGs and the utility grid. Anti-islanding is thus considered as an important constraint for grid-tied DGs.The IEEE 929 standard [1], the IEEE 1547 standard [2-3], the IEC standard [4-5] and the UL 1741 standard [4] states that islanding detection should be done within than 2 seconds from the occurrence of islanding.

The rest of the paper is arranged as follows, Section II presents islanding detection methods,Section III explains the proposed methodology,Section IV discusses the simulation results andSection V concludes the paper.

2. Islanding Detection Methods

Islanding detection methods (IDMs) are broadly classified as remote and local IDMs (12,13). The block diagram of IDMs is shown in Fig.2.below.

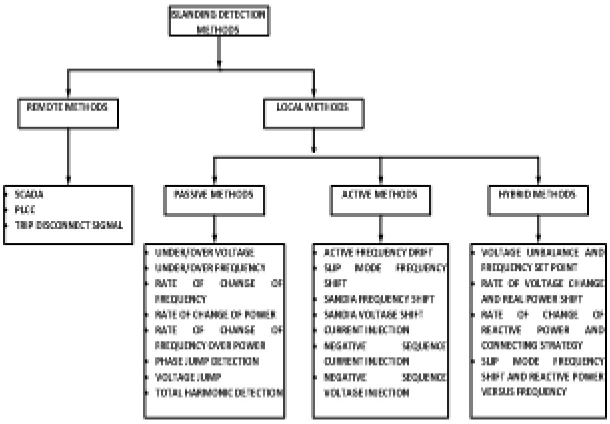


Figure 2: Block diagram of Islanding detection method

a) Remote islanding detection methods

Remote IDM, implemented on utility side, are concerned with monitoring grid side parameters, using communication technology to check the position ofprotection devices. Remote IDMs are classified as supervisory control and data acquisition (SCADA), power line carrier communication (PLCC) systems and trip (disconnect) signal. The performance of these methods are good and are also applicable to grid-tied multi DGs,the islanding occurrence can be efficiently detected, but the major disadvantage of this type of IDM is its high cost [14].

b) Local islanding detection methods

Local IDM, implemented on DG side are either inverter built or utility supported, concerned with the monitoring of inverter side parameters. The local IDMs are further classified as passive IDM, active IDM and hybrid IDM.

1) Passive islanding detection methods

Passive IDM checks grid voltage, grid frequency, and any variations of these parameters from the set threshold; activates over/under voltage, over/under frequency protection schemes. They donot inject any type of disturbance signal to the grid. These IDMs have a few disadvantages; fails to detect islandingcondition when voltage and frequency variation is small because of power balance between the load and the source,have large non-detection zone (NDZ), detection time of islandingis high, etc.,The passive IDMs are further classified as Under/Over voltage relay, Under/Over frequency relay, Rate of change of frequency etc.,[15].

2) Active islanding detection methods

In this type of IDM, a disturbance signal is injected; the change in parameters are monitored, any deviation from he set threshold would cause the relay to activate and disconnect the PV system from the grid. The main drawback of this method is that the power quality gets deteriorated due to variation in frequency or magnitude of voltage or current. The active IDMs are further classified as active frequency drift (AFD), slip mode frequency shift (SMFS), sandia frequency shift (SFS), sandia voltage shift (SVS), etc., [16]. The grid impedance is measured continuously, once the grid malfunctions or gets disconnected; islanding is formed due to sudden change in grid impedance. Application of this method to the multi-inverter systems is difficult. Amongst the aforesaid IDMs, AFD is gaining much attention,for a drift-up operation, a zero current segment(T_Z)is introduced, leading to slight distortion of the output current waveform. The current frequency is shifted slightly (δ_f = 0.5 to1.5Hz) higher than the previous cycle of the voltage frequency. The inverter current is made zero from negative semi-cycle end to the voltage positive zero crossingas shown Fig. 3.

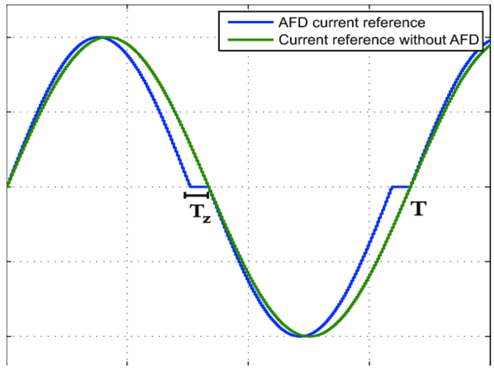


Figure 3: Current disturbance injected by AFD method

Chopping factor (cf) is defined as the ratio of zero time (T_Z) to half the period (T/2) of current reference without AFD, f is the frequency of the utility grid, $\delta_f$is the change in the frequency and given as

$$cf = \frac{T_Z}{T/2} = \frac{\delta_f}{f+\delta_f} \quad (1)$$

The steady state inverter reference current i*, and phase angle θ_{AFD} are given as

$$i^* = \sqrt{2}ISin\left[2\pi\left(f+\delta_f\right)\right] \quad (2)$$

$$\theta_{AFD} = \pi F T_Z = \frac{\pi\delta_f}{f+\delta_f} \quad (3)$$

Frequency is changed continuously as per the above equation, when the grid is connected, it opposes this change, once grid gets disconnected, OUF relay operates and island is formed thus protecting the entire system.

3) Hybrid islanding detection methods

Hybrid IDM overcomes the drawbacks of active and passive IDMs [17]. The hybrid IDMs are further classified as voltage unbalance and frequency set-point, rate of voltage change and real power shift, rate of change of reactive power and connecting strategy, etc.,The IEEE 929-2000 standard which focusses on recommendation for the islanding test procedures of the grid connected pv systems are as follows

a) At rated inverter output, the current total harmonic distortion (THD) should be below 5% of current fundamental frequency and the harmonics should be within the limits, it is tabulated below in Table.I

Table I: Distortion limits as per IEEE 519 - 1992 standard for six pulse converter

Odd	Limit (%)	Even	Limit (%)
3^{rd} - 9^{th}	< 4.0	2^{nd} – 8^{th}	< 1.0
11^{th} - 15^{th}	< 2.0	12^{th} – 16^{th}	< 0.5
17^{th} – 21^{th}	< 1.5	18^{th} – 22^{nd}	< 0.375
23^{rd} – 33^{rd}	< 0.6	24^{th} – 34^{th}	< 0.15
>33^{rd}	< 0.3	>34^{th}	<0.075

All the PV systems should work at a power factor more than 0.85 lagging or leading when the output is more than 10% of the rating of the system

b) The inverter should detect any voltage deviation at PCC and should operate within the trip time as it is tabulated below in Table.II

Table II: Response to abnormal voltage

RMS voltage at PCC		Maximum Trip Time (cycles)
Practice	Experiment (220V ref)	Practice
V<50%	V<110	6
50%≤V<88%	110≤ V<194	120
88%≤ V≤ 110%	194≤ V≤ 242	Normal Time
110%<V<137%	242<V<301	120
137%≤V	301≤ V	2

The inverter should stop feeding the utility line within 6 cycles, if grid frequency is below 59.3Hz and above 60.5Hz.

c) If the mismatch between the real power and the load is larger than 50% and the power factor of the islanded load is less than 0.95 lagging or leading, within 10 cycles or less the islanding should be detected. If the quality factor is 2.0 or less, the islanding should be detected within 2.0 seconds.

3. Proposed Methodology

PV inverters are designed so that the inverter output current isin phasewith the grid voltage to achieve unity power-factor inverter operation.The conventionalactive frequency shift (AFS) method when applied to multi inverter system has a drawback like quality factor of the loadwhich affects the islanding detection. The islanding detection may fail with high quality factor of the parallel RLC load as the shift in the voltage frequency cannot go beyond the set threshold frequency after islanding [18]. The R, L and C parameters in terms of voltage, quality factor and power is given as

$$R = \frac{V_{rms}^2}{P} \quad (4)$$

$$L = \frac{V_{rms}^2}{Q_f 2\pi f_0 P} \quad (5)$$

$$C = \frac{Q_f P}{V_{rms}^2 2\pi f_0} \quad (6)$$

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \quad (7)$$

The parallel RLC impedance load angle is given as

$$\varphi_{load} = arcTan\left(Q_f\left(\frac{f_0}{f} - \frac{f}{f_0}\right)\right) \quad (8)$$

$$Q_f = R\sqrt{\frac{C}{L}} \quad (9)$$

Q_f is the quality factor and f_0 is the resonant frequency of the parallel RLC load. When the grid gets disconnected, the load as seen from the inverter side would be purely resistive [19] and thus the impedance load angle, φ_{load} = 0. The current leads the voltage angle for a capacitive load, impedance angle would be negative and the frequency shifts upward. The negative impedance angle for each cycle shifts the frequency downwards as the voltage reaches zero crossing point slowly due to voltage phase hysteresis and SFS causes frequency offset in upward direction[20]. The frequency drift may not go beyond threshold with increase in load quality factor, frequency offset can develop more negative impedance angle and hence leading to islanding failure.

The NDZ characteristics on a two-dimensional plane can be expressed by Q_{f0} Vs. C_{norm} plane [21], describes NDZ

$$\frac{\tan\left(\frac{\pi}{2}cf_0+\frac{\pi}{2}K*0.5\right)}{Qf_0}-\frac{0.5}{f_0}+1<C_{norm}<\frac{\tan\left(\frac{\pi}{2}cf_0-\frac{\pi}{2}K*0.7\right)}{Qf_0}+\frac{0.7}{f_0}+1 \quad (10)$$

The active frequency drift with positive feedback (AFDPF) is implemented; it overcomes the long time required for islanding detection by taking a positive feedback of conventional AFD. The inverter control diagram with AFDPF method is shown in Fig.4.

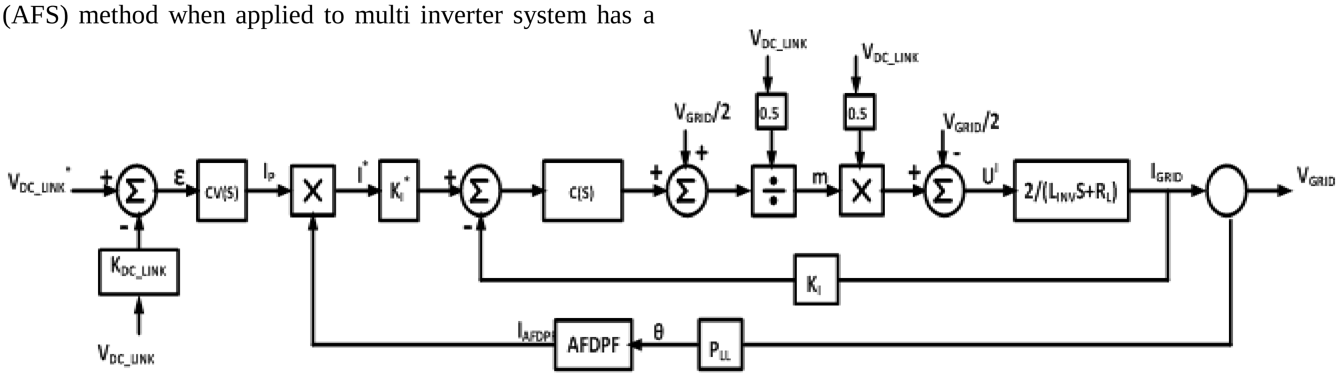


Figure 4: Inverter's control diagram with the AFDPF anti-islanding method

4. Simulation Results

The NDZ characteristics, obtained after simulating the equation (10) is depicted in the Fig.5 (a) and (b)

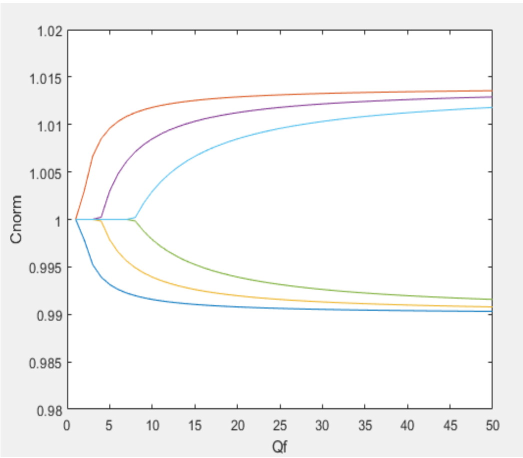
These Figures represents chopping factor (cf) characteristics for cf=0 and cf=0.02 respectively, it can be observed that size of NDZ doesn't get affected with increase in chopping factor, but merely drifts upwards. Setting of gain K has to be done wisely as its increase leads to decrease in size ofNDZ buts causes high PCC harmonic content, whereas reduction in gain K values lead to slower detection speed and increase in size of NDZ.

The following are the parameters of various elements of high penetrated grid tied PV system, grid voltage frequency is 220V/50Hz, threshold protection for frequency 50±0.5 Hz, parallel RLC load parameters, R = 48 Ω, L = 60mH and C = 168.86μF, positive feedback gain *K* is 0.07.

The inverter and the grid separation time are taken as 0.1s.

1) Scenario I

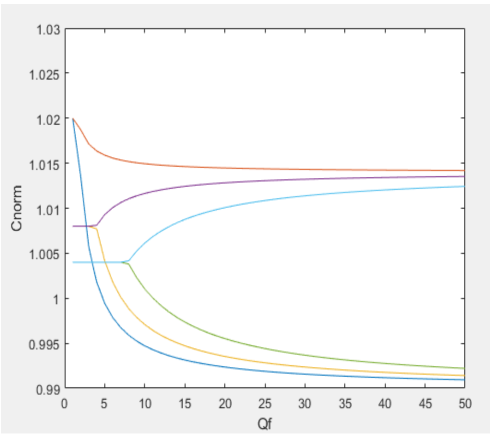
The NDZ characteristics forcf=0



(a)

2) Scenario II

The NDZ characteristicsforcf=0.02



(b)

Figure 5: NDZ characteristics for different chopping factors (a) cf=0 (b) cf=0.02

3) Scenario III

The simulation results for high penetrated grid tied PV system using presented methodology are shown in Fig.6. belowThe output of the inverter – I and inverter – II for a parallel RLC load havinga quality factor of 2.5 is shown.Using the presented methodology, islanding detection is done successfully, as per IEEE 1547 the inverter should stop delivering power within a time period of 2.0s.

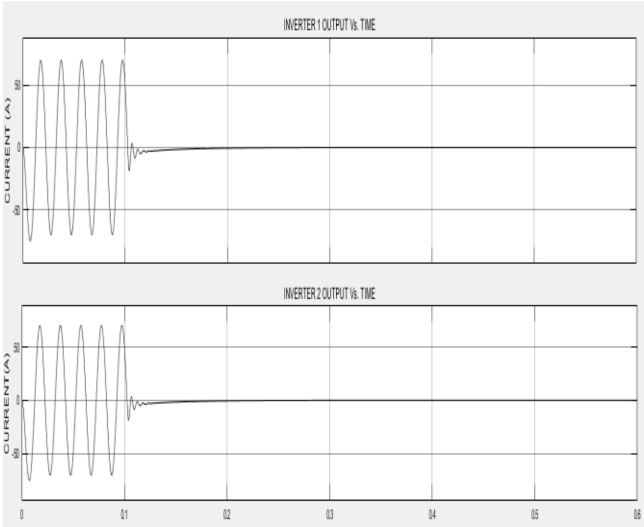


Figure 6: Inverter-1 & Inverter-2 output current at quality factor = 2.5

4) Scenario IV

The simulation results for high penetrated grid tied PV system using presented methodology are shown in Fig.7. below The output of the inverter – I and inverter – II for a parallel RLC load having a quality factor of 4.0 is shown. Using the presented methodology, islanding detection is done successfully, as per IEEE 1547 the inverter should stop delivering power within a time period of 2.0s.

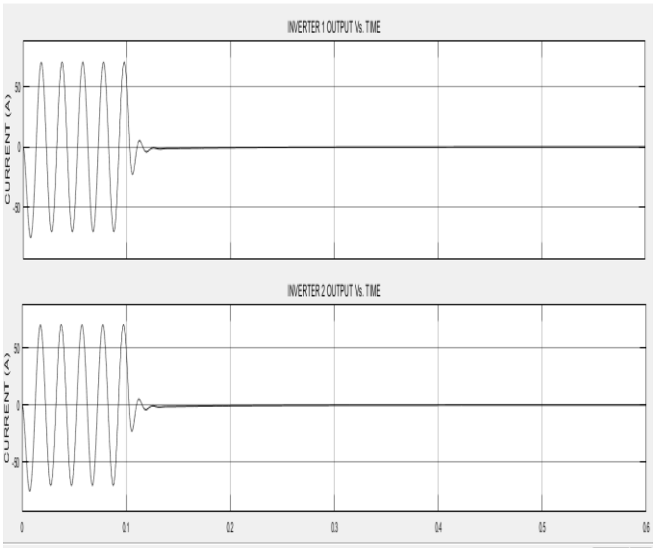


Figure 1: Inverter-1 & Inverter-2 output current at quality factor = 4.0

5. Conclusion

With increase in demand of electrical energy, DGs are coming up as an alternate energy sources connected to the grid. The DGs in the distribution network should have suitable protection scheme to protect the customers electrical equipments, grid and provide safety to the utility line-workers. The presented AFDPF method for the multi inverter system in the distribution system met the limits of islanding detection time and disconnected the inverters within the time limit, hence the PV system was tripped at the time of islanding.

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