



AN ISLANDING DETECTION METHOD FOR A GRID-CONNECTED DISTRIBUTION SYSTEM USING FUZZY CONTROLLER

¹B. RAMYA, ²Dr.A. Jaya Laxmi, ³T. VENKATESH

¹M. Tech (Electrical Power Engineering), ²Professor, ³Asst. Professor

Electrical and Electronics Engineering

JNTUH University College of Engineering, Science and Technology Hyderabad, India.

ABSTRACT: In natural disaster conditions, the disconnection between grid and load centres is the most probable condition. To maintain continuous power supply, it requires that loads should be connected to the locally available DERS which is known as islanding condition. In DGs that are directly connected to a grid, the islanding phenomenon can occur during unplanned disconnections from the grid. Specifically, islanding occurs when the grid-connected inverter of the DG and part of the local load are disconnected from the rest of the grid. If this phenomenon is not detected and the generation from a Photo Voltaic (PV) or other energy source remains operative, the islanded DG system remains energized by the inverter. The islanding phenomenon in PV systems is one of the most important problems in this area because it poses a safety hazard to repair and maintenance personnel. Grid connected photovoltaic systems have been paid more attention by people. The problem of anti-islanding is a key problem that threatens the secure operation of distributed generation (DG) system, so the system must have the function of timely detecting islanding. The traditional active frequency drift (AFD) method is not fast enough, and the total harmonic distortion (THD) is large, which greatly affect the output current quality. Hence, an improved active frequency drift detection method based on changing chopping factor (cf) is proposed in view of the above shortcomings of the traditional AFD method. In this method, the detection time is shortened, THD is reduced. The effectiveness and superiority of the proposed method are verified by Matlab/Simulink simulation.

KEYWORDS:-Islanding detection, Active Frequency drift, Non-Detection Zone, Total Harmonic Distortion.

I. INTRODUCTION

In the face of environmental concerns, energy security challenges, and the pursuit of sustainable development, the world's attention has increasingly turned to renewable resources as a fundamental pillar of the global energy transition. Unlike finite fossil fuels, renewable resources offer a replenishable and environmentally friendly source of energy that can help address pressing energy and climate-related issues. The landscape of energy generation and distribution is undergoing a transformative shift, with distributed generation (DG) emerging as a central player in the evolution of power systems. Distributed generation refers to the localized production of electricity, often using renewable or alternative energy sources, at or near the point of consumption. This departure from the conventional model brings forth a multitude of benefits, including enhanced energy efficiency, improved reliability, reduced transmission losses, and increased resilience against grid failures.

In the realm of distributed energy systems, the reliable detection of islanding events holds paramount importance. Islanding occurs when a portion of the electrical grid becomes electrically isolated from the main grid while still generating and consuming power locally. This kind of self-supply power system is called an island [1]. This phenomenon poses significant safety risks for utility workers and can lead to equipment damage due to unstable voltage and frequency levels [2]. Traditional islanding detection methods, which often rely on voltage and frequency relays, may prove insufficient in the context of modern distributed energy resources (DERs) due to their intermittent and dynamic nature.

Islanding in photovoltaic (PV) systems refers to a situation where a section of the PV system continues to generate power and supply electricity to local loads even when the grid connection is lost. Islanding can be hazardous to utility workers and equipment, and it can also lead to issues like overvoltage and equipment damage. To ensure safety and system stability, effective islanding detection methods are

essential. Several techniques have been developed to detect and mitigate islanding in PV systems. Here, we provide an introduction to some common islanding detection methods: Passive, Active and remote detection methods [3].

Passive islanding detection methods are "passive" in the sense that they do not actively inject signals into the system for detection purposes; instead, they rely on inherent characteristics of the power system to identify islanding events. Here are some common passive islanding detection methods: Rate of Change of Frequency (ROCOF), Rate of Change of Voltage (ROCOV), Voltage and Frequency Deviation, Harmonic Distortion, Impedance Measurement, Vector Shift Detection

Passive islanding detection methods are often preferred for their simplicity and cost-effectiveness. However, they may have limitations in terms of detection speed and sensitivity, especially in complex power system configurations. Passive detection has no effect on power quality, but it has a large non-detection zone (NDZ) and the threshold is difficult to determine. Combining multiple passive methods or integrating them with active detection techniques can enhance the overall reliability of islanding detection in distributed energy systems [4].

Active islanding detection methods are designed to actively monitor the system and promptly detect the occurrence of islanding events. Unlike passive methods that rely on inherent characteristics of the power system, active methods involve intentionally introducing disturbances into the system and analysing the system's response. These methods are often more responsive and can provide faster detection of islanding conditions. Active method has a smaller NDZ than passive method, but it has effect on power quality. Here are some common types of active islanding detection methods: Frequency-Watt (f-W) or Volt-Watt (V-W) Slope, Rate of Change of Frequency (ROCOF) with Injection, Impedance Measurement with Signal Injection, Active Frequency Drift and so on [5].

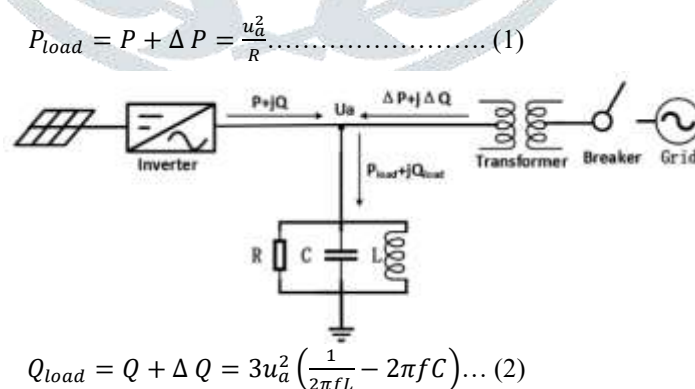
This method is effective because grid-connected inverters are designed to respond to changes in grid frequency or voltage. In an islanded condition, where the distributed energy resource is disconnected from the main grid, the response to such changes may deviate from the expected behaviour, providing a reliable indication of islanding.

Remote detection methods rely on communication systems to monitor and determine the status of circuit breakers. These methods generally offer a smaller Non-Detection Zone (NDZ) compared to other techniques, resulting in higher detection accuracy. However, this increased precision often comes with higher implementation costs. Common remote detection technologies include Power Line Carrier Communications (PLCC), Signal Produced by Disconnect (SPD), and Supervisory Control and Data Acquisition (SCADA) systems [6]. The remote detection method, while effective, is costly and therefore not suitable for small-scale power generation systems. Considering relevant regulations and the preceding analysis, a combination of active and passive detection methods is more appropriate for grid-connected photovoltaic (PV) systems. Among these, the active frequency drift (AFD) method is recognized as one of the most effective techniques for islanding detection [7]. To improve performance, this paper proposes an enhanced AFD method integrated with a fuzzy controller, which not only ensures reliable islanding detection but also helps reduce harmonic distortion in the system, thereby improving power quality.

II. ISLANDING STATE

When the breaker closes, the PV system connects to the grid. The active and reactive power supplied to the load are given by equations (1) and (2), where f and u_a represent the frequency and voltage at the coupling point before islanding.

Figure 1. Grid-connected photovoltaic (PV) power generation system



When the breaker opens, the PV system disconnects from the grid ($\Delta P = 0$, $\Delta Q = 0$). The active and reactive powers supplied to the load after disconnection are denoted as P' and Q' respectively. The frequency and voltage at the coupling point after islanding are represented by f' and U'_a .

$$P'_{load} = P = \frac{u_a'^2}{R} \dots (3)$$

$$Q'_{load} = Q = 3u_a'^2 \left(\frac{1}{2\pi f' L} - 2\pi f' C \right) \dots (4)$$

From equations (1)–(4), if the power between the PV system and the grid is perfectly matched, the frequency and amplitude remain unchanged. In this case, the positive detection method cannot detect islanding, creating a Non-Detection Zone (NDZ). However, when there

is a power mismatch before and after islanding, the amplitude and frequency of the coupling point voltage vary. The active detection method is used to prevent such matched conditions.

According to the GB/T 19939-2005 standard, the allowable frequency fluctuation range for a photovoltaic system under normal operation is 49.5 Hz to 50.5 Hz. The total harmonic distortion (THD) must be less than 5%, and the photovoltaic system must disconnect from the grid within 0.2 seconds [8].

III. ACTIVE FREQUENCY DRIFT METHOD

The Active Frequency Drift (AFD) islanding detection method operates by injecting a small amount of distortion into the system current. As illustrated in Fig. 1, the output current waveform of the inverter includes a slight distortion, resulting in a dead zone (t_z) between the positive and negative half-cycles. Here, T represents the period of the voltage at the point of common coupling (PCC). This intentional asymmetry helps in destabilizing the frequency under islanding conditions, thereby facilitating reliable detection.

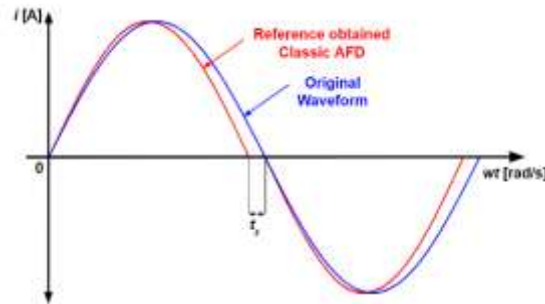


Figure 2. Current disturbance of AFD method

The chopping fraction (C_f) in the Active Frequency Drift (AFD) method is

$$C_f = \frac{t_z}{T} = \frac{2t_z}{T} \dots\dots\dots (5)$$

The chopping fraction shows how much the inverter's output current is disturbed. A bigger chopping fraction means more disturbance in the current waveform.

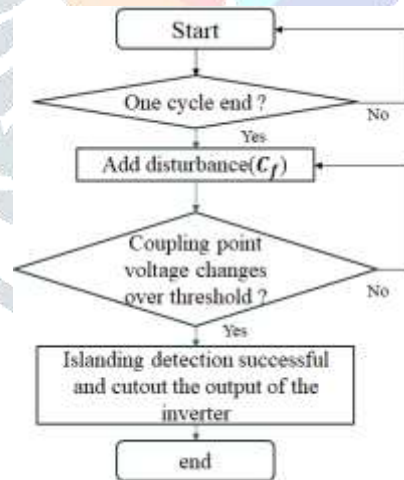


Figure 3. Flow chart of AFD

When the inverter is connected to the grid, its output voltage is synchronized and controlled by the grid voltage; therefore, the frequency at the coupling point remains stable. Once the inverter is disconnected from the grid, the coupling point voltage waveform begins to follow the distorted current waveform. As a result, the voltage waveform reaches the zero point either sooner or later than it would under a pure sinusoidal excitation, indicating that the coupling point frequency becomes slightly higher or lower than before. When this frequency deviation exceeds the set threshold, the over-frequency protection (OFP) or under-frequency protection (UFP) mechanisms are triggered, stopping the inverter's output. This process indicates that islanding has occurred, and the PV system is consequently disconnected.

Based on the type of disturbance introduced, the Active Frequency Shift (AFS) method can be categorized into two types: the Fixed Disturbance Active Frequency Shift Detection (AFD) method and the Active Frequency Shift Detection with Positive Feedback (AFDPF) method.

A. Active Frequency Drift

With a fixed chopping fraction (cf), the disturbance introduced in each cycle remains constant and affects the frequency of the coupling point voltage. However, the characteristics of the parallel RLC load also influence this frequency. If these two effects oppose each other,

the overall frequency change will be minimal, potentially causing detection failure. Figure 3 illustrates the flowchart of the AFD method. When two inverters operate in parallel using the same AFD technique but with opposite values of c_f , the disturbances can cancel each other out, preventing any noticeable change in the voltage frequency. This phenomenon is known as the dilution effect.

B. Active Frequency Drift with Positive Feedback

To overcome the dilution effect caused by the interaction between the load and the disturbance, the Active Frequency Drift with Positive Feedback (AFDPF) method is introduced. AFDPF enhances the traditional AFD technique by adding a voltage frequency variation, as shown in equation (6). Here, c_{f0} represents the initial chopping fraction, k is the feedback coefficient, f_v denotes the coupling point voltage frequency, and f_{grid} is the grid frequency during normal operation.

$$C_f = C_{f0} + k(f_v - f_{grid}) \dots \dots \dots (6)$$

It overcomes the dilution of the disturbance but if $C_{f0} > 0$ and $k(f_v - f_{grid}) < 0$, it also has the dilution and makes the detection fail.

C. An Improved Active Frequency Drift Method

The improved method addresses the limitations of both AFD and AFDPF by introducing variable parameters, as shown in equations (7) and (9). The symbol c_{f0} has the same meaning as the voltage frequency variation described in equation (7).

$$C_f = C_{f0} + k_o(f_v - f_{grid}) \dots \dots \dots (7)$$

$$C_{f0} = \begin{cases} C_{f0} & 49.8\text{Hz} \leq f_v \leq 50.2\text{Hz} \\ C_{f0} + \delta C_{f0} & \text{else} \end{cases} \dots \dots (8)$$

$$k = \begin{cases} k & 49.8\text{Hz} \leq f_v \leq 50.2\text{Hz} \\ k + \delta k & \text{else} \end{cases} \dots \dots \dots (9)$$

The improved method utilizes a chopping fraction symbol (C_{f0}) that aligns its direction with voltage frequency variation, allowing the disturbance introduced and load property changes to influence the frequency in a consistent manner. This makes it well suited for grids with diverse load characteristics, as both disturbances and load priorities shift the frequency in the same direction. Additionally, the improved method detects islanding faster than the standard AFD and AFDPF methods and operates with greater accuracy. By introducing smaller disturbances during normal grid operation, it keeps total harmonic distortion (THD) lower than those conventional methods, hence improving grid power quality and reducing the likelihood of false detection.

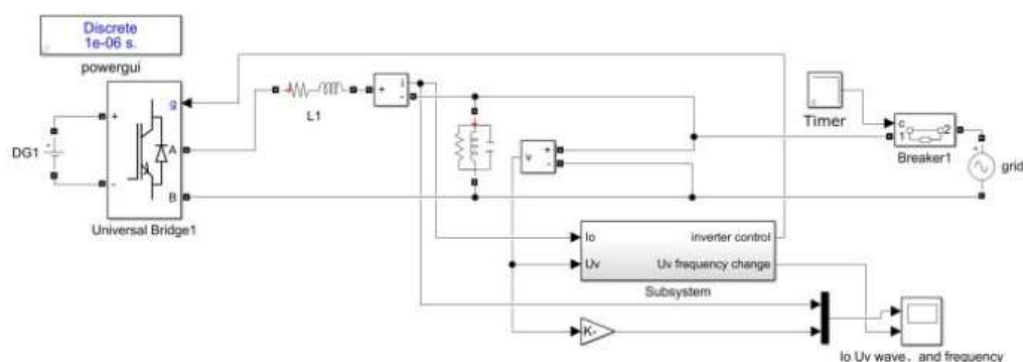
However, the improved approach is not without drawbacks. Its smaller disturbances can mean that, in scenarios where the AFDPF is used, the detection time may be slightly longer. Careful parameter selection is necessary to overcome this minor disadvantage and optimize detection speed without sacrificing power quality.

IV. PARAMETERS SELECTION

TABLE I

SIMULATION PARAMETERS			
Symbol	Value	Symbol	Value
$U_{DC}(PV)$	400V	$U_{AC}(RMS)$	220V
f_{grid}	50Hz	L (filter inductor)	$6 \times 10^{-3}H$
Breaker off time	0.1s	Total simulation time	0.5s
Q_f (capacitive load)	2.52	L (capacitive load)	$7.65 \times 10^{-3}H$
R (capacitive load)	6.01 Ω	C (capacitive load)	$1.35 \times 10^{-3}F$
Q_f (inductive load)	2.5	L (inductive load)	$7.5 \times 10^{-3}H$
R (inductive load)	6.01 Ω	C (inductive load)	$1.3 \times 10^{-3}F$

V = volt, H = henry, F=farad, Hz=hertz, s=second, Ω =ohm.



(a) photovoltaic system

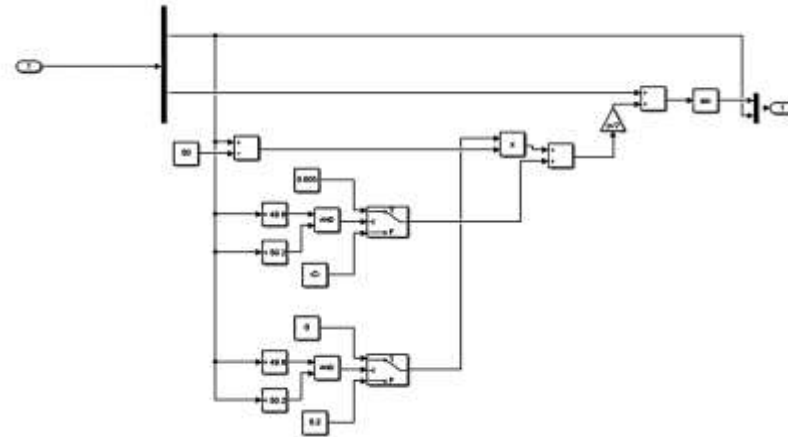
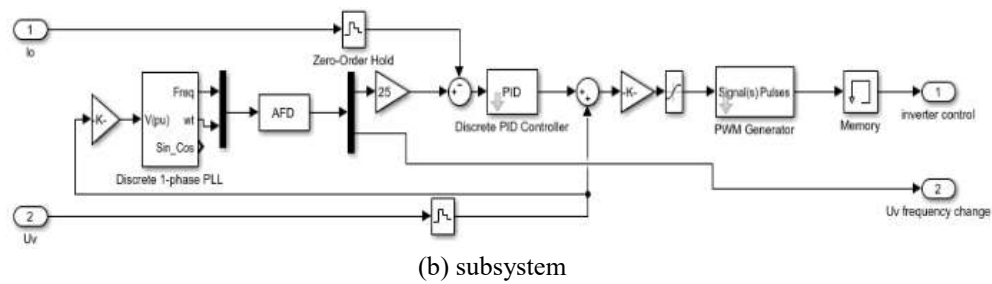


Figure 4. Grid-connected photovoltaic system

V. SIMULATION RESULTS

A grid-connected photovoltaic system can be modelled and analysed using SIMULINK, as depicted in Figure 4. The specific simulation parameters utilized for this system are detailed in Table I.

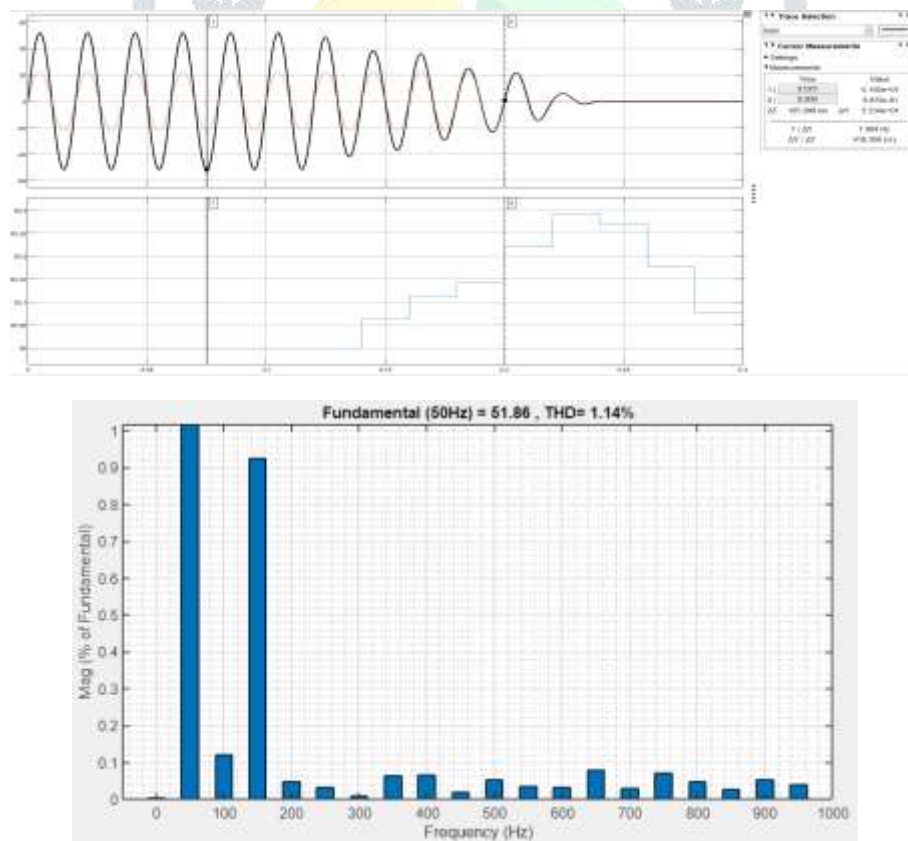
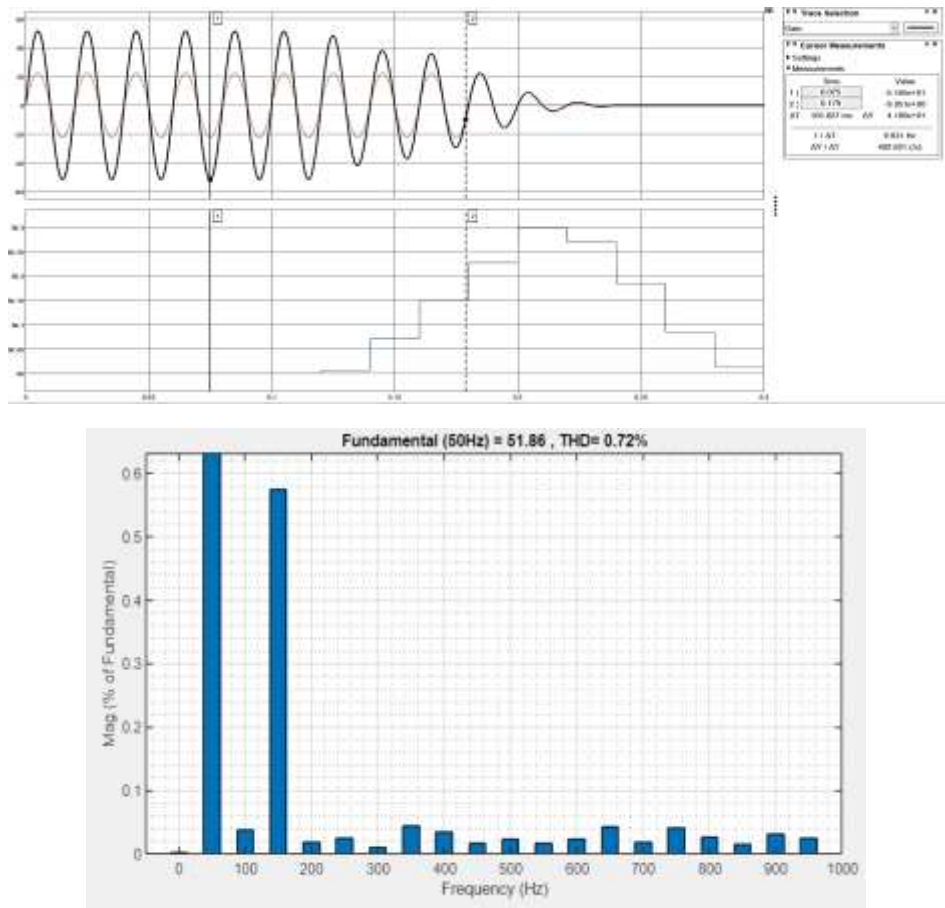


Figure 5. Simulate results of AFD



a) Inverter output current and coupling point voltage waveforms (b) frequency change diagram (c) harmonic analysis
Figure 6. Simulate results of Improved AFD

TABLE II
SIMULATION RESULTS (AFD)

Capacitive load			Inductive load		
cf	THD (%)	T(s)	cf	THD (%)	T(s)
$0.02+0.1\Delta f$	2.61	0.402	$0.02+0.1\Delta f$	2.84	0.179
$0.02+0.2\Delta f$	2.61	0.22	$0.02+0.2\Delta f$	2.86	0.179
$0.01+0.1\Delta f$	1.87	0.262	$0.01+0.1\Delta f$	2.86	0.179
$0.01+0.2\Delta f$	1.86	0.201	$0.01+0.2\Delta f$	2.24	0.179

T is the time the system detects islanding.

TABLE III
SIMULATION RESULTS (Improved AFD)

c_f	Capacitive load		c_f	Inductive load	
	THD (%)	T(s)		THD (%)	T(s)
$C_{fo} = 0.01, k = 0$ $\Delta C_{fo} = 0.01, \Delta k = 0.1$	2.20	0.201	$C_{fo} = 0.01, k = 0$ $\Delta C_{fo} = 0.01, \Delta k = 0.1$	2.68	0.2
$C_{fo} = 0.01, k = 0$ $\Delta C_{fo} = 0.01, \Delta k = 0.2$	2.20	0.201	$C_{fo} = 0.01, k = 0$ $\Delta C_{fo} = 0.01, \Delta k = 0.2$	2.68	0.2
$C_{fo} = 0.01, k = 0.1$ $\Delta C_{fo} = 0.01, \Delta k = 0.1$	2.53	0.201	$C_{fo} = 0.01, k = 0.1$ $\Delta C_{fo} = 0.01, \Delta k = 0.1$	2.68	0.179
$C_{fo} = 0.005, k = 0$ $\Delta C_{fo} = 0.015, \Delta k = 0.2$	1.65	0.201	$C_{fo} = 0.005, k = 0$ $\Delta C_{fo} = 0.015, \Delta k = 0.2$	1.70	0.198

T is the time the system detects islanding.

The improved technique, when compared with the AFDPF method, offers better power quality with lower total harmonic distortion (THD), though it does result in a marginally longer detection time that still remains within acceptable limits. Simulation results confirm that the improved method operates as expected theoretically.

In summary, the AFDPF method addresses the large non-detection zone (NDZ) present in conventional AFD. The improved approach further resolves the single-direction disturbance issue seen in AFDPF and achieves lower THD, thus minimizing its effect on power quality. As a result, the THD produced by the improved islanding detection method is reduced, ensuring only a minimal impact on overall grid quality.

VI. CONCLUSION

With the rapid expansion of new energy sources, an increasing number of distributed generation (DG) units are being integrated into the grid, heightening the importance of advanced islanding detection techniques. Islanding occurs when a portion of the power system continues to be powered by DGs even after disconnection from the main grid, which can create safety, reliability, and power quality concerns. Traditional islanding detection approaches often struggle with large non-detection zones (NDZ) and can adversely impact the quality of power delivered to consumers.

The improved islanding detection method stands out by significantly shrinking the NDZ compared to conventional Active Frequency Drift (AFD) and AFDPF (Active Frequency Drift with Positive Feedback) methods, resulting in more reliable and responsive detection. Moreover, it imposes a smaller disturbance on the power system, thereby maintaining better overall power quality and reducing total harmonic distortion (THD). While the detection time for this enhanced method is somewhat longer than that of standard AFD and AFDPF approaches, it still meets the required standards for disconnecting PV systems, ensuring safe isolation during islanding events. Notably, the improved method's effectiveness has been validated only through simulation studies using tools such as Simulink; no real-world experimental implementation has yet been undertaken. This underscores the need for further research and practical testing before deploying the method in actual power systems, especially to confirm its performance across varied operating conditions and with diverse grid configurations.

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