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A New Islanding Detection Technique using Ensemble Empirical Mode Decomposition

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Abstract – Penetration of distributed generation (DG) is rapidly increasing but their main issue is islanding. Advanced signal processing methods needs a renewed focus in detecting islanding. The proposed scheme is based on Ensemble Empirical Mode Decomposition (EEMD) in which Gaussian white noise is added to original signal which solves the mode mixing problem of Empirical mode decomposition (EMD) and Hilbert transform is applied to obtained Intrinsic mode functions(IMF). The proposed method reliably and accurately detects disturbances at different events.

Index Terms—Distributed Generation (DG), Empirical Mode Decomposition (EMD), Ensemble Empirical Mode Decomposition (EEMD), Intrinsic Mode Function (IMF).

I. INTRODUCTION

Deployment of distributed generation (DG) is greatly observed over a decade as conventional energy sources are at a breakneck pace and also the power demand escalated. The integration of distributed energy resources such as photovoltaic (PV), hydro, wind and tidal to utility grid called Distributed generation. Power quality disturbance and islanding situation becoming more complex due to high penetration of DERs in conventional grid. When any faults or system collapse occurs fast and accurate methods are required to detect disturbance and micro grid is to be isolated from the main grid without injuring transmission line. Islanding need to be detected within 2 seconds according to IEEE 1547 standards which helps DG stabilized through a smooth transition. Islanding detection methods are classified as local techniques (active, passive and hybrid) and signal processing based techniques [1]. Active methods induce harmonics into the grid system [2][3] while passive methods have large non detection zone (NDZ) [5][6] as they are ineffective for active power and reactive power mismatch of less than 15% and 5% respectively [4]. In this regard, advanced signal-processing-based methods are taken to count to eliminate NDZ by improving performance without inducing disturbances to grid system. The Fourier transform (FT) is a fast detection technique for only stationary signals but the majority of PQ disturbances are non stationary. FT technique is further advanced as the short-time FT it applies stationary window function but needs computational resources [7].

Predefined Gaussian window approach is used in S-transform (ST) but visualization of the spectrum has limitations [8]. In and Time-Time transform and Hyperbolic S-Transform, detection accuracy goes on decreases as the computational complexity is higher for transients and harmonics [9].In the wavelet transform (WT) detection capability is decreased due to improper selection of mother wavelets [10]–[13]. Discrete wavelet transforms (DWT) transfer non uniform frequency decomposition if noise is present in the input signal. It is not fully self-adaptive and disturbance detection is not well founded. Empirical mode decomposition (EMD) uses sifting process for obtaining intrinsic mode functions (IMF) it improves detection performance but suffers from mode mixing and aliasing problem [14]. To overcome the limitations of EMD and on addition of white Gaussian noise develops Ensemble Empirical mode decomposition (EEMD) [15][16]. In the paper EEMD technique is used for early fault detection and Hilbert transform is applied further as it provides better detection by improving amplitude and frequency properties.

The layout of the paper is in the following way. In Section II, theory of the proposed method for fault detection is given. In Section III, islanding and non islanding events with simulation results are discussed. In Section IV, the conclusions drawn are presented.

II. PROPOSED METHOD

A. Empirical Mode Decomposition

EMD is one of the best advanced signal processing method for analysing non-stationary signals and non-linear signals in which sifting process decomposes input signal into a finite and small number of intrinsic mode functions (IMFs). The steps for extracting IMF from input signal are:

1. Identify local maxima and minima of the input signal X(t).

2. Upper envelope ($e_{max}(t)$) and lower envelope ($e_{min}(t)$) are obtained by applying cubic spline interpolation to local maxima and minima respectively

3. On calculating mean of the envelopes, $m(t) = (e_{max}(t) + e_{min}(t))/2$.

4. Extract $h_1(t) = X(t) - m(t)$.

5. If h_1 (t) does not satisfy the conditions of IMF, then repeat steps 1–4 taking $h_1(t)$ instead of X(t) till the new h1(t) satisfies the conditions of an IMF which is the resultant IMF is c1(t).

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Calculate the residue, $r_1(t) = X(t) - c_1(t)$.

The conditions for IMF are

a) For a data set, the number of extrema and the zero crossings must be equal or differ by one .

b) At any point, the mean value of the envelope is zero.

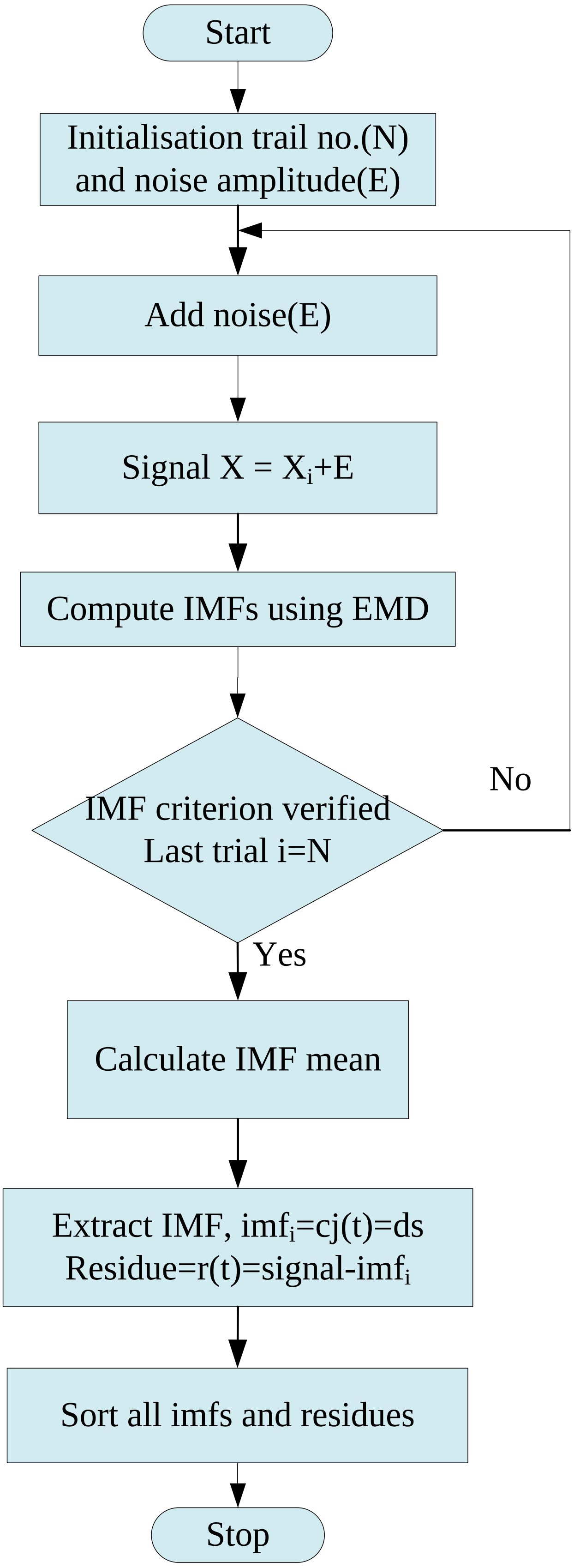

Fig.1 Flowchart of EEMD

B. Ensemble Empirical Mode Decomposition

Aliasing and mode mixing are the problems of EMD. To overcome the problem of EMD white noise is added as White Gaussian Noise (WGN) has zero mean value and hence resultant ensemble sum of IMFs contains zero noise which makes EEMD more superior over traditional EMD method as the IMFs are closer to the original signal. Thus accurate results are obtained through EEMD. In flowchart of EEMD shown in figure first set the number of ensemble iteration (N) and standard deviation (SD) of white Gaussian signal. On adding original signal X (t) with WGN signal E (t), (having zero mean and constant SD) we get $X_n(t)$

$$X_n(t) = X(t) + E \qquad (1)$$

EMD algorithm is applied to $X_n(t)$ and different IMFs are obtained. The obtained IMFs contain white noise which can be eliminated by calculating mean of IMFs. Hilbert transform is applied for feature extraction from IMFs obtained from EEMD decomposition of the signal. Hilbert transform of any signal is given in equation (2)

$$H[c(t)] = \int \frac{c(\tau)}{t-\tau} \qquad (2)$$

Hilbert transform of signal c(t) is orthogonal to the original signal c(t) and has 90^0 phase shift in frequency domain.

III. SIMULATION OF PROPOSED SYSTEM

The test system shown in Figure 2 is simulated with the Sim-power systems environment to show the performance of method proposed and its performance strictly accepts the IEEE 1547. The output of the PV array is given to DC/DC boost converter. The duty cycle of DC/DC converter is controlled by maximum power point tracking (MPPT) controller. MPPT controller helps to extract maximum power from the PV array during bad weather conditions also. The output of this boost converter is connected to the 3 phase inverter. The inverter converts DC input to AC output. The AC output of the inverter is synchronized to the grid at the distribution level through LC filter because LC filter is to eliminate the harmonics from the inverter output. It also helps to supply required reactive power.

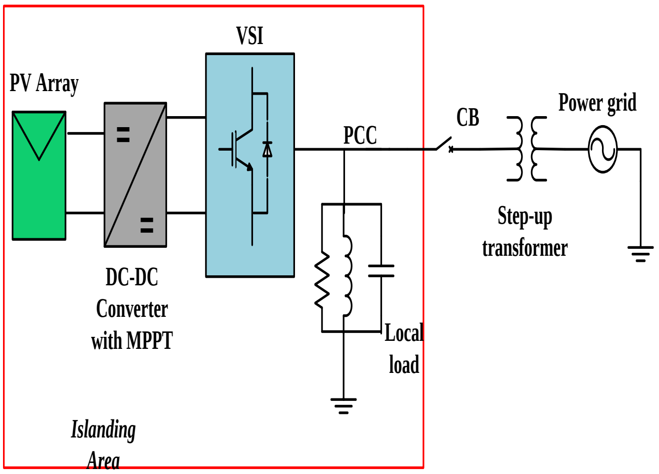

Fig.2.Single line diagram of proposed system

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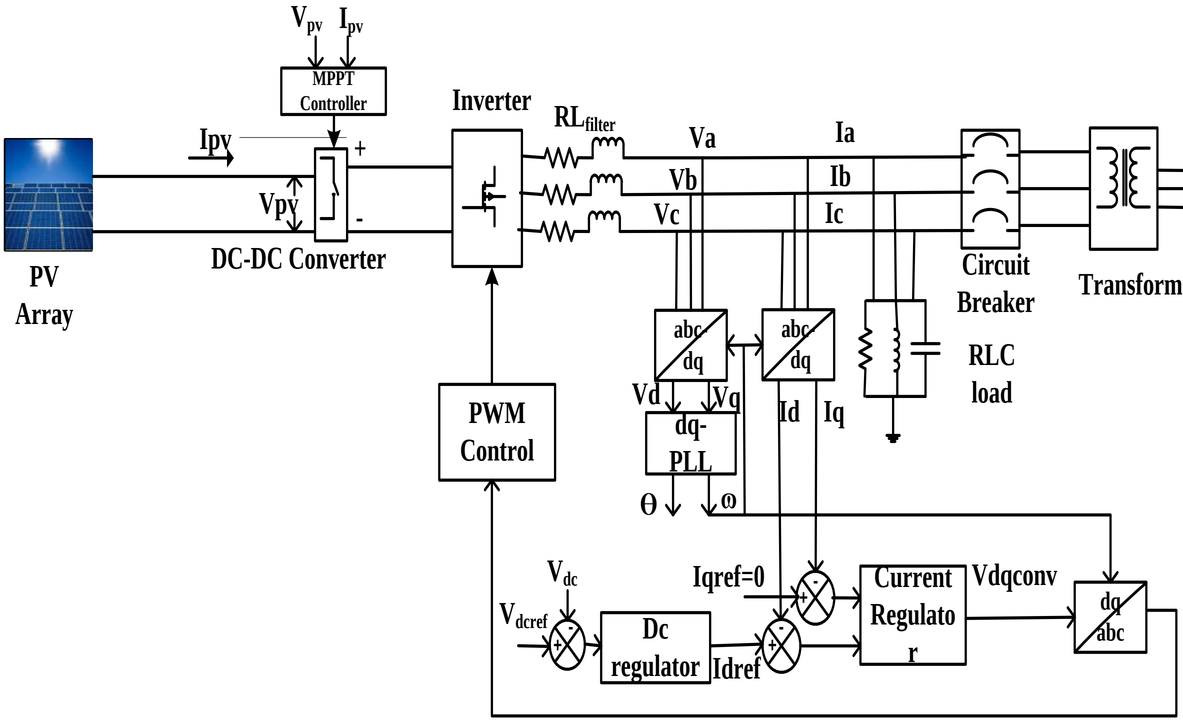


Fig.3.Complete diagram of system taken

The CB is initially closed and the DG is in the grid connected mode. The 3 phase circuit breaker (CB) at PCC is switched on i.e., opened when increases beyond threshold which creates islanding condition. DG is separated from the grid and supplies power to local load. Ensemble empirical mode decomposition detects the islanding condition.

For the PV shown in figure 3 the ensemble empirical mode decomposition is applied for the voltage taken at the point of common coupling at different events such as three phase fault, line to ground faults, real power mismatch, reactive power mismatch and zero power imbalance conditions and islanding and non-islanding cases are observed in MATLAB/SIMULINK, R2018b.

Name of the Parameter	Value
PV array rated power output	100KW
Quality Factor	2.5
Filter resistance	1.2ohms
Filter Inductance	100mh
Transformer Rating	0.4/120
Transformer power rating	2500
Frequency	50

Table.1 Parameter specification

IV. RESULTS AND DISCUSSIONS

On applying ensemble empirical mode decomposition the second IMF of the signal for zero power imbalance condition. The plot clearly shows that at 1 sec the amplitude has increased and our aim is to give trip signal to circuit breaker after 3 sec of fault detection. Different cases such as zero power imbalance condition, real power mismatch, three phase and phase to ground faults as well as load switching detection conditions. For the system taken the ensemble empirical mode decomposition with Hilbert transform is applied in different cases such as

1. Islanding at zero power imbalance condition
2. Islanding detection when faults occur
3. Detection of load switching
4. Detection of islanding at real power mismatch case
5. Detection of islanding at reactive power mismatch case

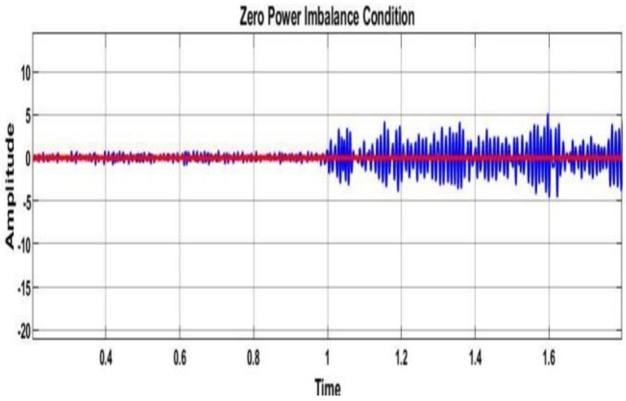


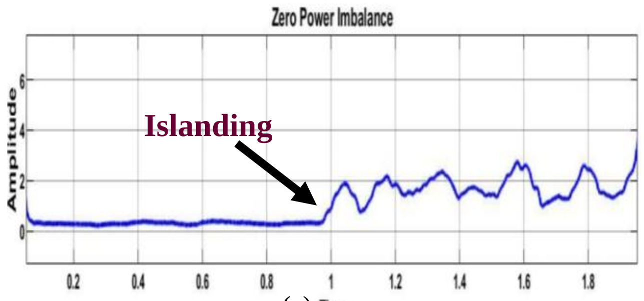
Fig.4.Second IMF for zero power imbalance case

A. Detection of Islanding and non-islanding conditions in different cases

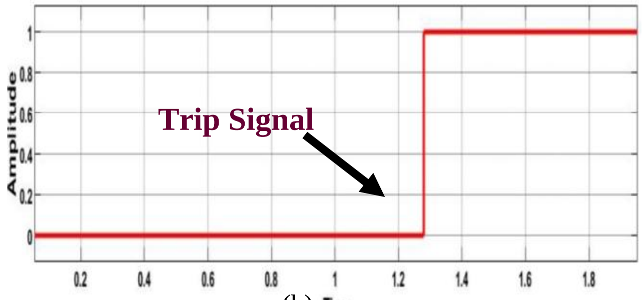
1. Islanding at zero power imbalance condition

At zero power imbalance condition i.e., when power at DG is same as the load power then the change in both the powers is zero which is a dead end case where we cannot find the case of islanding as both the powers are same.

On going towards EEMD method and following the algorithm shown in figure1 finds the zero imbalance condition with negligible NDZ (Non-Detection Zone). Plot shown in figure 5 at 1 sec the fault has been observed in the system as the amplitude goes on increases as after 3 sec delay of fault occurrences the trip signal is given to the circuit breaker shown in figure6 at 1.3 sec the trigger is given to breaker. Thus the method detects the zero power imbalance condition at nearly zero non-detection zone.



(a) Time

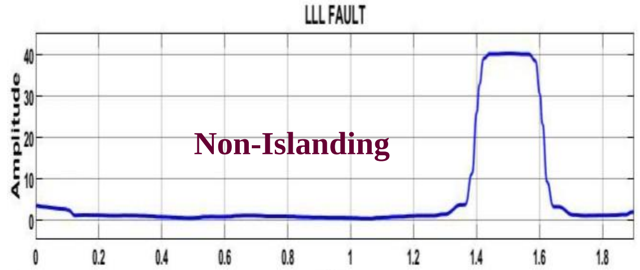


(b) Time

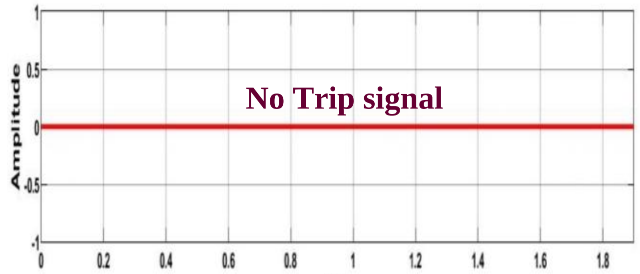
Fig.5. Zero power imbalance case (a) Output of proposed method fault detection at 0.95 sec (b) Detection of the imbalance condition at 1.3 sec.

2. Islanding detection when Faults occur

The two types of faults namely three phase fault(LLL) and double line to ground(LLG) faults are studied.



(a) Time

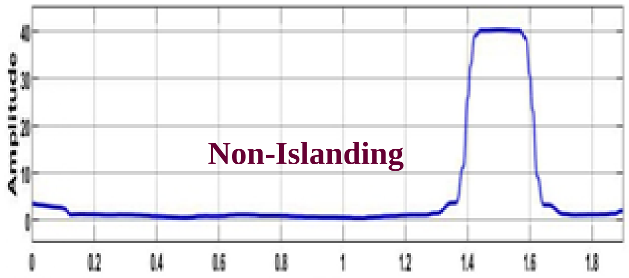


(b) Time

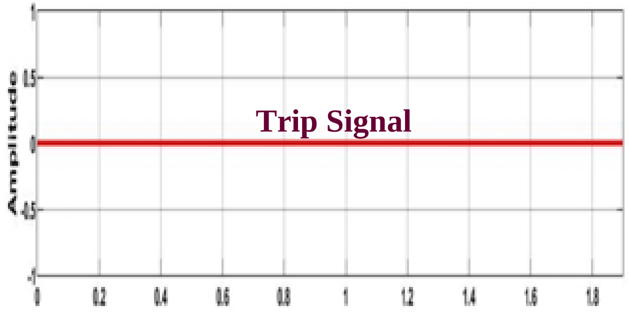
Fig.6. LLL fault case (a) LLL fault detection (b) non islanding case

LLL fault is symmetric fault and the occurrence of symmetric faults in the system is only 5% but it is a major fault case so to the system taken the LLL fault is posed at 1.38 sec as the fault persists less than 2sec shown in figure6(a) it is a non islanding case and the islanding is not detected shown in figure6(b).

LLG (Double Line to Ground fault) is an asymmetrical fault. Nearly 20% of the faults are double line to ground faults. The LLG fault is applied to the system at 1.3 seconds shown in figure 7(a)



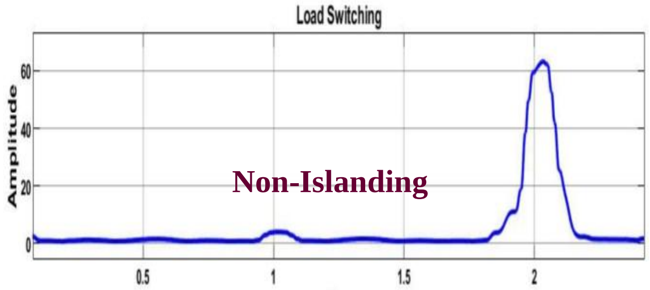
(a) Time



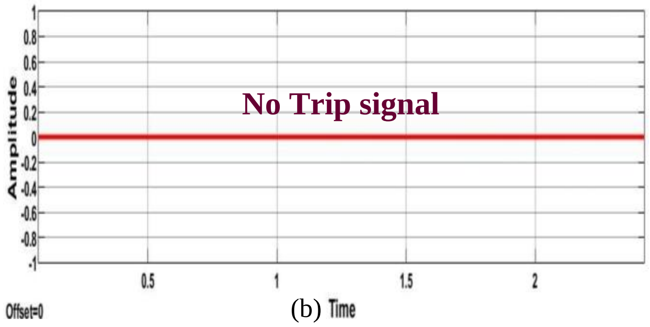
(b) Time

Fig.7. LLG fault case (a) LLG fault detection (b) Trigger to the breaker.

3. Detection of load switching



(a) Time



(b) Time

Fig.8. Load detection (a) Detection of load (b)non islanding

Load switching is the main case where it is an non islanding case to be detected by the system but not triggered as load switching is not a faulty case.

It is also detected by the proposed method and the figure 8(a) which clearly shows the load switched in at 1 sec and switched out at 2 sec that condition is non-islanding shown in figure 8(b). So, no signal is sent to circuit breaker at PCC as it is a non islanding condition.

4. *Reactive power mismatch condition*

Reactive power is required in order to drive the active power in the transmission and distribution systems. It helps to convert to useful work. The case where reactive power mismatch occurs must be detected. Figure 9(a) detects the imbalance condition of both reactive power and as shown in figure 9(b) the islanding is detected.

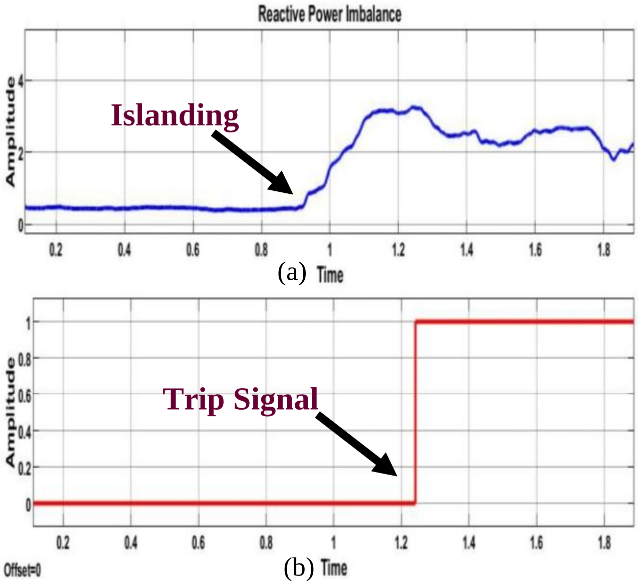


Fig.9. Reactive power Imbalance (a) Reactive power mismatch detection (b) Trip signal to breaker

5. *Real power mismatch condition*

Real power helps do the useful work it is required to drive the system. The mismatch in real power is the tedious case needed to be detected to defend the system from faulty case

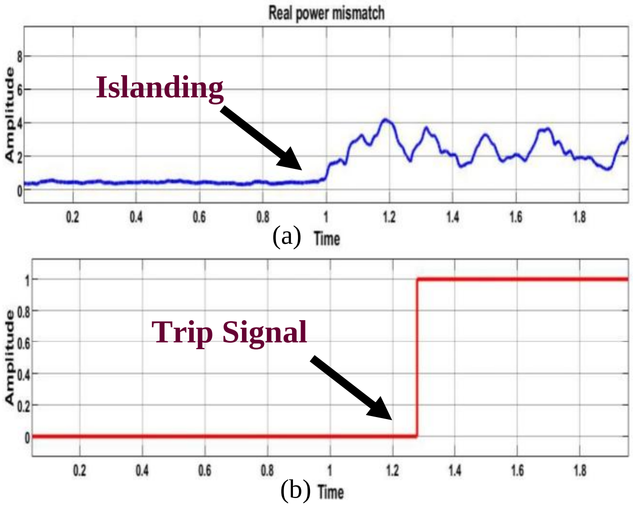


Fig.10. Real power imbalance (a) Real power mismatch detection (b) Trip signal to breaker

Figure 10(a) detects the imbalance condition of both reactive power and as shown in figure 10(b) the islanding is detected.

EEMD detects different events clearly with zero NDZ (Non-Detection Zone) which can be keenly observed by the above discussion.

Case	Detection Time	Islanding Detection
Zero power imbalance condition	Negligible	Islanding Case
Fault case (a) LLL (b) LLG	-------	Non-Islanding
Load detection	-------	Non-Islanding Case. Load switched in at 1sec and switched out at 1.8sec
Reactive power mismatch	Negligible	Islanding Case. At 0.9sec reactive power mismatch detected and at 1.23 sec trip signal given to breaker
Real power mismatch	Negligible	Islanding Case. At 1sec real power mismatch detected and at 1.3 sec trip signal given to breaker

Table.2 Discussion of Results

V. CONCLUSION

Proposed scheme (EEMD) in which gaussian white noise is added to original signal which solves the mode mixing problem of Empirical mode decomposition (EMD) and Hilbert transform is applied to obtained Intrinsic mode functions(IMF) firmly detects different events such as three phase faults, line to ground faults, reactive power mismatch, real power mismatch and zero power imbalance cases showing non detection zone (NDZ) is negligible Thus proposed method is robust and accurately detects disturbances at different events.

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