Faster Islanding Detection of Microgrid Based on Multiscale Mathematical Morphology

Pravati Nayak*, Arya Avilash **‡, Ranjan Kumar Mallick***

*Department of EE, Assistant Professor, Siksha ‘O’ Anusandhan deemed to be university

**Department of EEE, , Siksha ‘O’ Anusandhan deemed to be university

***Department of EEE, Professor, Siksha ‘O’ Anusandhan deemed to be university

(pravatinayak@soa.ac.in , arya.avilash1997@gmail.com, rkm.iter@gmail.com)

‡ Ranjan Kumar Mallick; Bhubaneswar, India Tel: +91 797 804 5548; rkm.iter@gmail.com

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Abstract- Faster and reliable islanding detection of microgrid is necessary to protect the equipment and maintenance personnel. Voltage and frequency are two important parameters needs to be controlled in microgrid; Voltage and frequency stability of microgrid depends merely on main grid during grid connected mode and depends on individual controllers during islanding mode. This research proposes a time domain technique based on multi-scale mathematical morphology (MMM) for islanding detection. The proposed technique uses multiscale dilation-erosion difference filter (MDEDF) with peak value of the signal. The performance of the proposed technique is validated in IEEE-13bus system with different cases such as mismatch in real power, reactive power, load switching, motor switching; L-G fault. The results validate the accuracy and efficacy of the proposed technique and also compared with recently published work.

Keywords- Islanding detection; multi-scale dilation-erosion difference filler; microgrid; mathematical morphology.

1. Introduction

The rapid growth of renewable sector reduces the green house effect and global warming. The most popular renewable energy generations are solar photovoltaic and wind farms consisting of double fed induction generators (DFIGs), etc. These are known as distributed energy resources (DGs). Integration of these sources in conventional power system are desired to maintain voltage and frequency stability, power quality which is necessary for any power utility company. Microgrid can be regarded as a group of DGs and loads with small power ratings with energy storage and has an ability to operated on islanding and grid connected mode [1]. Distributed generation is an new approach that enables modern technology to produce electricity nearby consumers. DGs can provide electric power at lower cost with higher reliability and security with less environmental consequences than traditional power generation [2, 3]. Reliability of microgrid is a measure of the system’s overall ability to produce and supply of electrical power as Compared to conventional grid. DGs have many kinds of operating characteristics, such as increased reliability with distributed generation, increase efficiency with reduced transmission length and easier integration of alternative energy sources. However, there are many issues should be taken care before the DG units are connected to the distributed networks. These problems include voltage fluctuation, switching transients, power quality issues, and possible occurrence of islanding [4]. The disconnection of main grid from DGs is named as islanding. Islanding detection is achieved by observing significant deviations in to the system’s output parameters. Islanding is the condition in which a distributed generator continues to supply power a location even though electrical grid power is no longer exist. Unintentional islanding occurs due to over voltage, grid fault or wrong CB operation, equipment damage [5]. Therefore, effective solution is required to detect accurately the islanding occurrence event and disconnect microgrid from the main Grid within a minimum specified time. Different protecting devices and control equipments are needed for the islanding detection.

Islanding basically of two types, intentional and unintentional. Unintentional islanding detection is more challenging as compared to intentional islanding. As per the specified criteria in IEEE-1547 standard, islanding condition should be detected within 2secs of its occurrence [6]. Islanding detection techniques are classified as remote and local methods. The remote methods are communication based and managed by main grid, which does not affect power quality but the implementation is costly [7]. Local techniques are further classified into active and passive techniques [8]. Local techniques process voltage, current, frequency at the nearby DG location for feature extraction and Islanding detection. Active techniques use voltage and current potrubution and create power quality issues in Grid [9]. Active slip mode frequency shift and active frequency drift clearly discussed in [10].

Passive techniques are not effective while real power mismatch is below 15% and reactive power mismatch is below 5%[11]. Large non detection zone (NDZ) is the major drawback of passive techniques [12]. The signal processing techniques are gaining more popularity by reducing NDZ and without hampering the power quality. Wavelet transform (WT) was applied to negative sequence voltage signals to detect islanding with the help of energy and standard deviations [13]. In [14,15] S-transform was used to detect islanding condition.

Several passive methods using signal processing techniques has been tried in recent research to reduce NDZ such as mathematical morphology is used in [16] to detect islanding condition in distributed network with high wind power penetration. Author has used a new operator called as mathematical morphology ratio index(MMRI) to discriminate islanding and non islanding condition, and the reported detection time is 20ms with 0% active power mismatch. In [17] orthogonal empirical mode decomposition (OEMD) is used to detect islanding and other power quality disturbances. Though author is successful in detecting islanding and non-islanding events but silent about time of detection.

Recently an harmonic signature based islanding detection is proposed in[18] ,where Kalman filter is used to extract and calculate the harmonic content in the voltage signals at the DG terminals .The variation of selected harmonic distortion differentiate between islanding and non islanding cases. The Demerits of Kalman filter is in noisy condition it fails to correctly measure the harmonic contents. A novel islanding detection method has been proposed in [19] using combination of rate of change of exciter voltage and circuit breaker at DG location. In [20] a ridgelet probabilistic neural network is proposed to classify islanding and other grid disturbance issues. Author has used modified differential evolution technique to train the neural network. In[21] author has proposed a new computational intelligent method known as multi gene genetic programming to classify the islanding and non islanding events. Islanding detection using change of reactive power in a synchronous generator based DGs proposed in [22].An overview of PV-based energy system is discussed in [23].An grid connected wind energy system is simulated in [24] for different wind speeds. In[25]simulation of multi-module converter has been investigated for hybrid energy systems. An open source data acquisition system in laboratory has been studied in[26].Design of solar energy sources for political movement is discussed in[27]. Sliding mode control based MPPT with VSC converters in solar PV based system is discussed in[28]. In [29] mathematical morphology-based dilation-erosion differential filter (DED) is used on RMS voltage signal to detect islanding and other power quality events, the reported detection time is below 17ms. Therefore, it is desired to have an efficient islanding detection technique with approximately zero non-detection Zone (NDZ) with small detection time. This research proposes a time domain technique based on multi-scale mathematical morphology (MMM) for islanding detection. The proposed technique uses multiscale dilation-erosion difference filter (MDEDF) with peak value of the signal. . Proposed signal processing method uses simple math operators with very less computational burden and large data transfer is not required. The efficacy of proposed method is tested in a IEEE-13 bus distribution network for validation in various operating conditions, such as Islanding detection with no power mismatch, real power mismatch, reactive power mismatch. Power quality disturbances such as induction motor switching and capacitor switching are simulated for validation and test the efficacy of proposed technique.

2. Model investigated

IEEE 13-bus model distribution system is considered for simulation study [17] and the single line diagram is shown in "Fig.1".The distribution model consists of two wind farms connected at bus B9 and B13, one wind farm consist of four wind turbines. One PV system consists of 100 modules connected in series and 200 modules in parallel, is connected to bus B10. There are six identical loads connected at different buses. The distribution lines are modelled as π-section and distance between two consecutive buses are taken as 10km. The main Grid is connected to bus B1. The ratings of each component are given in "Table 1"

The system is operated as balanced system with 50Hz frequency. Under islanding condition DGs are capable of supplying loads independently. Power balance equations of 13-bus system depicted in figure-1 are given below

$$\sum_{i=1}^{n} P_L + \Delta P = \sum_{i=1}^{n} P_{Gi} \qquad (1)$$

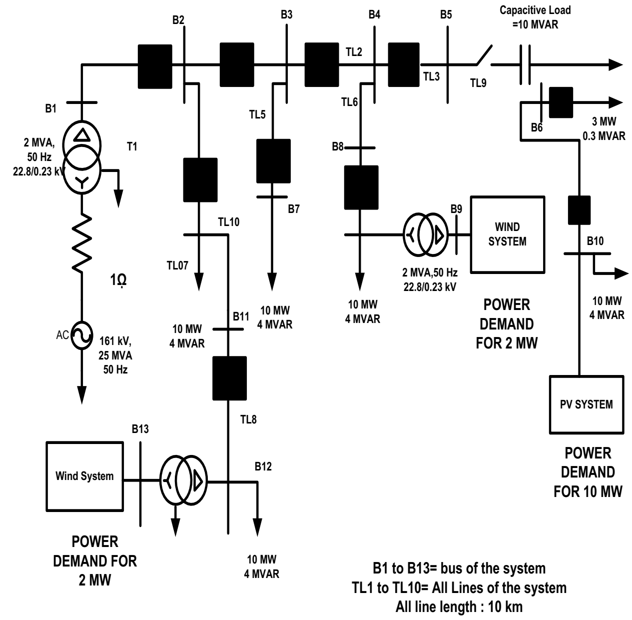

Fig.1.Single line diagram of IEEE 13 bus system.

$$\sum_{i=1}^{n} Q_L + \Delta Q = \sum_{i=1}^{n} Q_{Gi} \qquad (2)$$

$$S_L = V_{PCC}^2 / Z_L = P_L + jQ_L \qquad (3)$$

Where, P_L and Q_L are real and reactive power of loads. P_{Gi} , Q_{Gi} are real and reactive power generation of independent DGS connected in microgrid. ΔP is the real power difference between loads and generation, ΔQ is the reactive power difference between reactive power demand of loads and generation. When ΔP is zero means real power demanded by loads met by DGs.

Table 1. IEEE 13-Bus System Specification

Sl .no	Specifications of IEEE- 13 bus system	
1.	Main Grid	50MVA,120KV,50HZ
2.	Wind turbines	2MW(each)
3.	Loads	10MW,4MVAR (each)
4.	PV modules	10MW

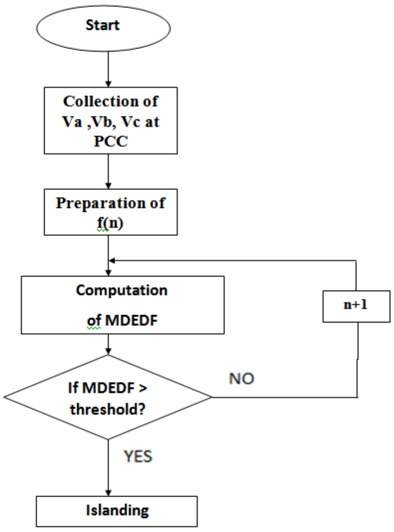

Fig.2. Flow Chat of Proposed Islanding Detection Technique

3. Multi-scale mathematical morphology

Mathematical morphology is an efficient tool for the in-depth analysis of geometrical structures in a quantitative approach. It comprises of conceptual theories, several operators of non-linear signals along with special algorithms so as to extract dimensional information of geographical object [30]. The non-linear signal processing operators (NLSPO) not only helps in extracting the useful signal but also eliminates the artifacts. In fact, islanding signals processed by mono-scale operators is analogues to gray-scale morphology. This directs to an extremely efficient method for deriving the necessary components from the contaminated signal even without past knowledge regarding the frequency spectrum. This frequency independency is a very tempting feature for noise reduction in islanding signal of micro-grid.

Classical single scale analysis [31] with fixed SE heavily based upon prior knowledge which is often unavailable is special cases. Hence, it unable to extract impulsive features [32], when information distributed over multiple scales due to lack of completeness. The benefits of multi scale mathematical morphology (MSMM) in extracting the FAULT features are proven in [33]. The complete steps of MSMM can be expressed as below,

Let us consider F(n) as the discrete one dimensional signal of length N , G(m) as the structuring element(SE) of length S and (S<N). The symbols $\oplus, \Theta, \circ$ and $\bullet$ are known as dilation, erosion, opening and closing operator in mathematical morphology.

Suppose, G and α are the unit structure element and scale respectively where α(α = 1, 2, 3,…., α_{max}). Now the SE at a scale range of α can be written as,

$$\alpha G = \underbrace{G \oplus G \oplus G \oplus \ldots\ldots \oplus G}_{\alpha-1\text{times}} \qquad (4)$$

The erosion and dilation operators in scale α for f(n) can be expressed as,

$$F \Theta \alpha G = \underbrace{F \Theta G \Theta G \Theta \ldots. \Theta G}_{\alpha-1\text{time}} \qquad (5)$$

$$F \oplus \alpha G = \underbrace{F \oplus G \oplus G \oplus \ldots. \oplus G}_{\alpha-1\text{time}} \qquad (6)$$

The corresponding dilation erosion difference filter in multi-scale (MDEDF) analysis can be expressed as,

$$MDEDF_{\alpha} = F \oplus \alpha G - F \Theta \alpha G \qquad (7)$$

The opening and closing operators in scale α for F(n) can be expressed as,

$$F \circ \alpha G = F \Theta \alpha F \oplus \alpha G \qquad (8)$$

$$F \bullet \alpha G = F \oplus \alpha G \Theta \alpha G \qquad (9)$$

The corresponding difference operator in multi-scale analysis can be expressed as,

$$MDIF_{\alpha} = F \bullet \alpha G - F \circ \alpha G \qquad (10)$$

4. Proposed Detection Technique

The proposed islanding detection techniques uses multiscale mathematical morphology based dilation-erosion difference filter (MDEDF) to detect the islanding event after processing the collected voltage signal at PCC from bus B2 as shown in

Figure1.The simulation model is built on MATLAB SIMULINK of version2015a. The processor used in the work is Intel Core -i3,64 bit,1.70GHz. All islanding and non-islanding events are simulated for a duration of 1.2sec.Since the model consists of wind farms & PV modules ,the controllers take around 0.2 sec to bring the voltage steady state condition. All the events are initiated at time t=0.6sec. The peak vale of the collected phase voltages are extracted using Fourier analyzer block in simulink. All the signals are passed through the proposed dilation erosion difference filter in multi-scale (MDEDF) as given in “Eq. (7)”to detect the changes in the signal, if the MDEDF exceeds the specified threshold value then it is declared as islanding condition. The main objective behind using multiscale morphology is to exract transient features of islanding and other power quality events and detect the changes in the voltage waveform accurately so that NDZ can be reduced nearly equals to zero. The choice of structuring element SE depends on the dimension, type and frequency of the signals [34]. The optimal structuring element SE used here as G(m)=[0.01,.01------- 0.01] having 30 elements in so many trials. F(n) is the peak value of the signal. The detail steps of islanding detection are shown in flow chart Figure 2

4.1. Simulation and Results:

Case-1: Islanding detection with no power mismatch

In this case circuit breaker connected to main grid is opened at t = .6s, assuming some fault in grid side. Microgrid operated under islanding mode, DGs are capable of supplying load demand so no power is being transferred from grid to microgrid. As load impedance is being fixed, it tries to draw constant real and reactive power, as grid is no more supplying the reactive and real power support, voltage supposed to fall. During islanding condition there is a fall in voltage as identified in simulation and also there is a transient in voltage during transition between grids connected mode and islanding mode. This voltage transient captured by multiscale dilation erosion difference filter (MDEDF) as given in “Eq. (7)”. The peak value of voltage signals are collected at point of common coupling at bus B2, then MDEDF is applied. The peak value of the signal and MDEDF are shown in Figure-3. MDEDF has no unit, it is evident from figure that MDEDF crosses threshold 1000 at .615secs. So, the detection time is 15milisec. This case is considered as base case and threshold is fixed at 1000 for all other islanding and non-islanding cases.

Case-2: Islanding detection with Real power mismatch

The meaning of power mismatch in an islanding network is power supplied by the main utility grid to microgrid prior to the occurrence of islanding. Real power mismatch can be obtained by varying the real power drawn by the load keeping reactive power drawn as constant. In this case simulation is carried out for different real power mismatches such as 5%, 15%, and 20%. In the similar manner the CB at bus B1 is opened at 0.6sec and peak values of voltage signals collected at PCC then MDEDF is applied. The peak value of the signals and MDEDF are shown in “Fig.4”,“Fig.5”, &“Fig.6”, respectively. In “Fig.4”it is observed that MDEDF is crossing the threshold at .615 sec i.e. detection time is 15 msec. In“Fig.5”, MDEDF is crossing the threshold also at .615sec i.e the detection time is 15 msec. In “Fig.6” MDEDF is crossing at .614sec, the detection time is 14msecs. It is observed that as the power mismatch increases the detection time reduces.

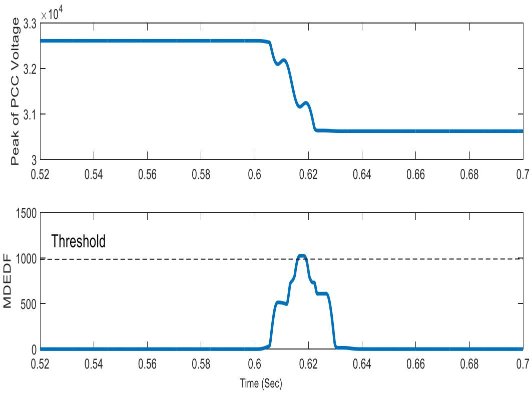

Fig.3. Peak of PCC voltage and output of MDEDF with no power mismatch

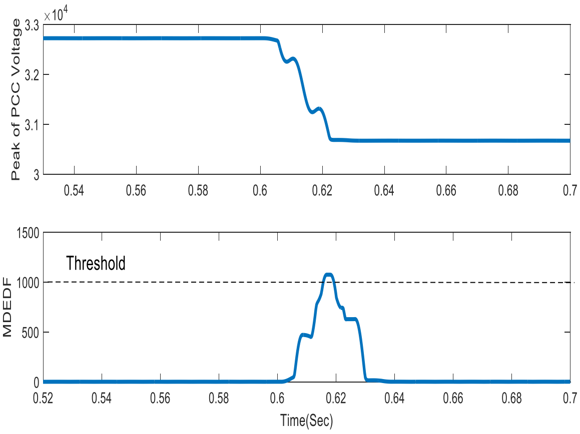

Fig.4. Peak of PCC voltage and output of MDEDF with 5% Real Power Mismatch

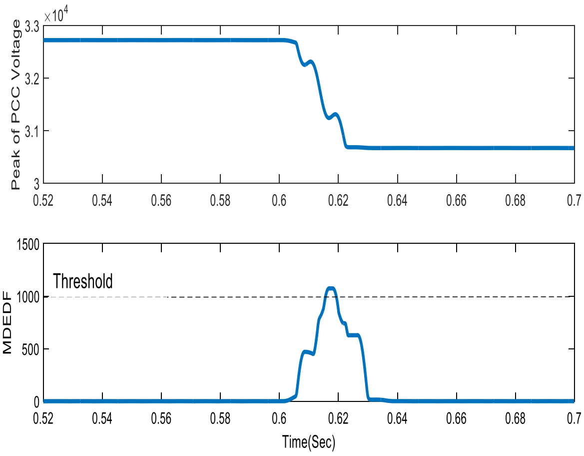

Fig.5. Peak of PCC voltage and output of MDEDF with 15% Real Power Mismatch

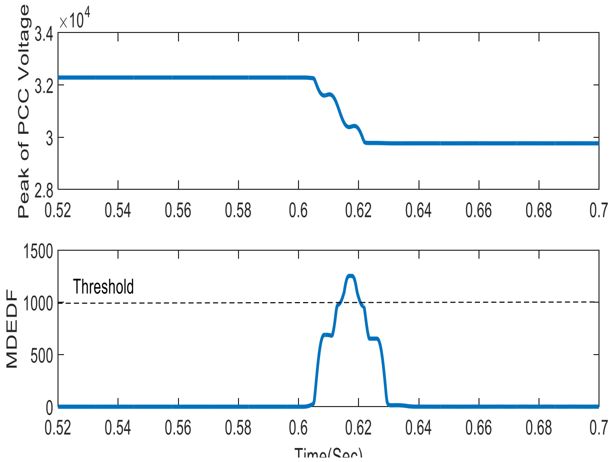

Fig.6. Peak of PCC voltage and output of MDEDF with 30% Real Power Mismatch

Case-3: Islanding detection with Reactive power mismatch

For different reactive power mismatches such as 5%, 15%, 30% the simulation is carried out. The CB at bus B1 is opened at 0.6s for all cases and peak value of voltage signals are collected at PCC, then MDEDF is applied on the signals. The plots of peak value of signals and MDEDF are shown in “Fig.7”, “Fig. 8” & “Fig. 9” respectively.

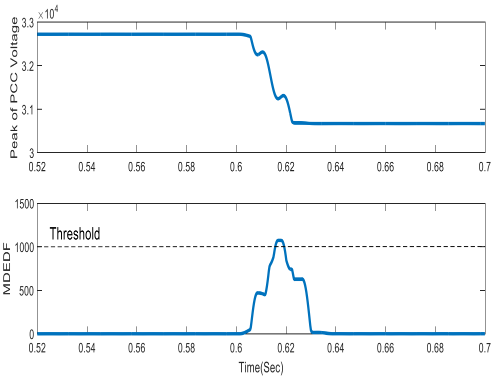

Fig.7. Peak of PCC voltage and output of MDEDF with 10% Reactive Power Mismatch

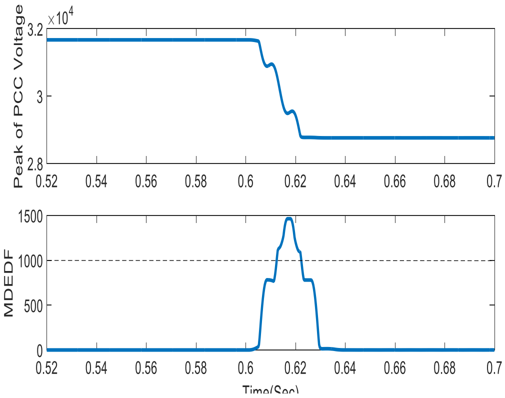

Fig.8. Peak of PCC voltage and output of MDEDF with 20% Reactive Power Mismatch

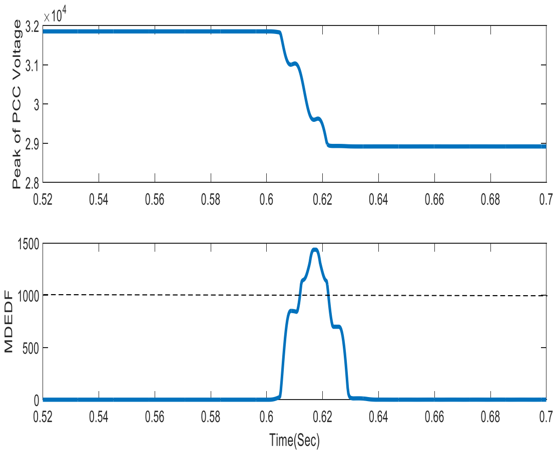

Fig.9. Peak of PCC voltage and output of MDEDF with 30% Reactive Power Mismatch

From the figures it is evident that in all cases the MDEDF curve crosses the threshold before .615sec i.e the detection time is below 15msec.

Case-4: Capacitor switching

When high value of capacitor is switched on bus B5 at t=.6secs. The capacitor bank supplies reactive power, thereby there is an increase in voltage at PCC, this voltage increase must differentiated from islanding condition. “Fig.10” shows the variation of peak amplitude of voltage and output of MDEDF. It is clear that MDEDF is below the threshold value 1000, so it is treated as non-islanding condition.

Case-5: Induction motor switching

Large induction motors draw heavy current during starting i.e draws reactive power from line, it leads to fall in voltage at PCC, and this condition may be treated as islanding condition by conventional relays. It is desired that it must be detected as non-islanding condition. “Fig.11” shows the variation of peak amplitude of voltage as well as MDEDF, it is evident from figure that during starting period MDEDF is below the threshold value 1000. The proposed method is verified

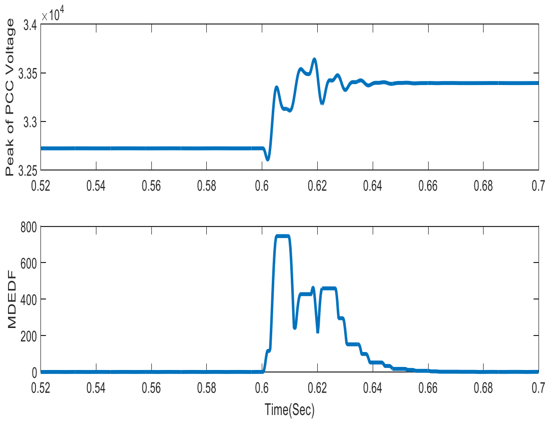

Fig.10. Peak of PCC voltage and output of MDEDF with Capacitor Switching

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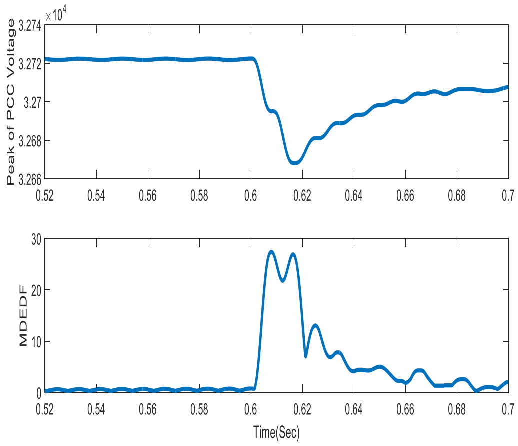

Fig.11. Peak of PCC voltage and output of MDEDF with Motor Switching

5. Conclusion

It is highly desired to disconnect DGs from distribution network to prevent damage and personnel safety during islanding condition. In this proposed research, a novel islanding detection technique is presented based on multi scale morphological operators named as MDEDF to reduce NDZ approximately zero with faster detection time. Proposed signal processing method uses simple math operators with very less computational burden and large data transfer is not required. The efficacy of proposed method tested in a IEEE-13 bus distribution network for validation, where different operating conditions are Islanding detection with no power mismatch, only real power mismatch, only reactive power mismatch below 30%.It is verified from simulation and results that the proposed research is able to detect islanding condition within 15ms and also able to discriminate other power quality events such as capacitor switching and induction motor switching effectively. In future this method can be implemented in multi DG environment due to its less computational burden and higher accuracy with smaller detection time .Further weighted multiscale morphology may be tried for improvement in accuracy of islanding detection.

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