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An Efficient Passive Islanding Detection Method for Integrated DG System with Zero NDZ

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Abstract- In this paper an efficient passive islanding detection scheme is presented for renewable distributed generation (DG). Islanding is caused if DG supplies power to load after disconnecting from the grid due to system failure or an act of nature. As per the DG interconnection standards, it is required to detect the islanding within 2 seconds after islanding with the equipments connected to it. In this paper, the islanding is detected with the combined changes of rate of change of positive sequence voltage (ROCOPSV) and rate of change of positive sequence current (ROCOPSC). The islanding is detected if both the values of ROCOPSV and ROCOPSC are more than a predefined threshold value. The test system results carried on MATLAB shows the performance of the proposed method for various islanding and non islanding events with different power imbalances. Various non islanding cases like capacitor switching, load swithching are also clearly differentiated with islanding events. Islanding detction is posible at balanced islanding with zero non detection zone (NDZ) by proposed technique.

Keywords: Islanding detection; Balanced islanding; ROCOPSV; ROCOPSC; NDZ; Distributed Generation (DG).

1. Introduction

Renewable power generation systems are increasing in daily life to meet the global energy consumption demand. Renewable power generation system which is connected at the consumer level is called DG [1]. The main problem with such DG is islanding. The part of a power system which is electrically separated but supplied by nearer DG is called islanding in power system [2]. The islanding is unsafe to field persons and equipments connected because the servicing persons are not mindful that the frame up is connected and supplying with DG near. The main causes of such unintentional islanding are due to the failures detected by the grid, accidental opening of circuit breaker (CB) at the grid, intentional opening of CB for maintenance, human errors and an act of nature [3]. Main grid interfacing rules listed in the Table-I, needs that it is necessary to disconnect the DG source within 2 seconds, because if the island load is more or less, then it leads to variations in the voltage, frequency, current, THD, active, reactive powers outside the standards, which may hazardous to customer loads connected to it and sometimes for DG [4-6]. The islanding detection methods are classified as local and remote techniques; again the local techniques are classified as active, passive and hybrid techniques. By injecting small disturbance at PCC for some cycles and observing the deviations in the output signal active methods will detect the islanding [7-11]. In the grid connected system, the system absorbs the local disturbance and considerable deviations are not observed. However, more deviations are observed in the output signal if the system is islanded. Active methods are more efficient than passive methods with less NDZ, but they are affecting the power quality [12-16]. The range of values where a passive detection method fails to detect islanding is called NDZ [17]. In passive techniques, regional parameters such as voltage, frequency, current, phase angle, THD are monitored at the PCC, if there are changes beyond a certain threshold level, then islanding is detected [18]. The hybrid methods are the combination of both active and passive methods. When a passive method suspects islanding, active method will confirm the islanding. These methods have less NDZ than passive methods, but they degrade the power quality [19-24].

Rate of change of frequency (ROCOF) [25], [47], the rate of change of active power (ROCOAP) [26], phase angle difference [27], the rate of change of voltage (ROCOV) [28], the rate of change of reactive power ROCORP [29], over under voltage / over under frequency (OUV/OUF) [30] are some passive methods, they are suffering with the large NDZ, and fails to detect islanding at low or zero power imbalance conditions. The combination of any two passive parameters is used to reduce the NDZ, like ROCOF and output power [31], ROCOV and THD [32], ROCOV and power factor [6], [28], ROCOV and ROCOF [33], [54] ROCOAP combination with ROCORP [34]. The transient component based, THD based islanding techniques are presented [55-56], [62-64], will reduces the NDZ. These methods will reduce the NDZ to less compare to single parameter passive techniques.

Proposed inventive passive islanding detection method is presented for wind DG integrated power system with ROCOPSV and ROCOPSC. The islanding is detected if both the values of ROCOPSV and ROCOPSC are more than a predefined threshold value. Different islanding and non islanding events are simulated to evaluate the performance of the proposed method at balanced islanding. The results shows that, this method is separating between islanding events with non islanding events and also it is detecting islanding at zero power imbalance condition with zero NDZ. The rest of the paper is structured as a test system under study is presented in section II. In section III, the proposed islanding detection method is presented. Results discussion and comparison with existing methods are presented in section IV. Lastly, the conclusions is drawn in section V.

Table - I. Island detection time, frequency and voltage ranges of various standards

Standard	Quality factor	Detection time (ms)	Range of frequency	Voltage range
IEEE 1547	1	t < 2000	$59.3 \le f \le 60.5$ Hz	$88\% \le V \le 110\%$
IEC 62116	1	t < 2000	$f_0 - 1.5 \le f \le f_0 + 1.5$	$85\% \le V \le 115\%$
Korean Standard	1	t < 500	59.3 Hz $\le f \le$ 60.5	$88\% \le V \le 110\%$
UL 1741	≤1.8	t < 2000	Setting value	Setting value
VDE 0126-1-1	2	t < 200	47.5 Hz $\le f \le$ 50.2 Hz	$80\% \le V \le 115\%$
IEEE 929-2000	2.5	t < 2000	$59.3 \le f \le 60.5$Hz	$88\% \le V \le 110\%$
AS47773-2005	1	t < 2000	Setting value	Setting value

2. Test System under Study

Conceptual analysis of the islanding detection process is shown in Fig.1. If the DG feeds power to a local load after disconnecting from the main grid, its called an electric islanding. The DG is integrated to the grid with transformers and CB. When the inter-tie CB is opened, the islanding is caused with industrial area shown with inner circle with dotted lines. If the main CB is opened, the islanding is occured with local load and industrial area. The voltage and currents are input to the proposed detection process.

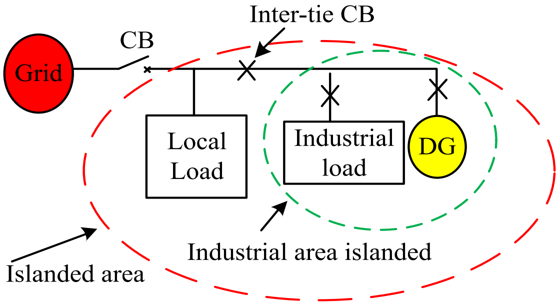

Fig. 1. Principle of islanding detection

If an islanding is suspected, then the CB is opened to protect customer equipment and DG. The single line diagram of the test system is shown in Fig.2. It consists of wind power generation systems of 9 MW and a woodword governer model of IEEE AC1A- type exciter 3.125 MW. To generate 9 MW, six 1.5 MW wind turbines are connected (6*1.5= 9 MW) with an output voltage of 575 volts and 60Hz frequency. These two DGs are connected in parallel and integrated to the 1000 MVA, 25 KV grid with transformers, transmission lines and local loads.

3. Proposed Method of Islanding Detection

3.1 Mathematical modelling of proposed method

When the system is in grid connected mode, the voltages and currents at PCC are 120^0 apart from each other and are balanced. After islanding, these voltages, currents and other passive parameters like frequency, THD, active power, reactive power, sequence components, phase angle between the components are unbalanned and deviate from standard values. The sequence analyzer will separate the positive, negative and zero sequence components of unbalanced voltages and currents obtained at PCC. The zero sequence components present only when the system is associated with ground due to fault in the main grid or DG. The negative sequence components present during the islanding operation or fault switching. The positive sequence components will present in all modes. The symmetrical components of voltages at PCC are defined as (1)

$$\begin{bmatrix} v_{a0} \\ v_{a1} \\ v_{a2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (1)$$

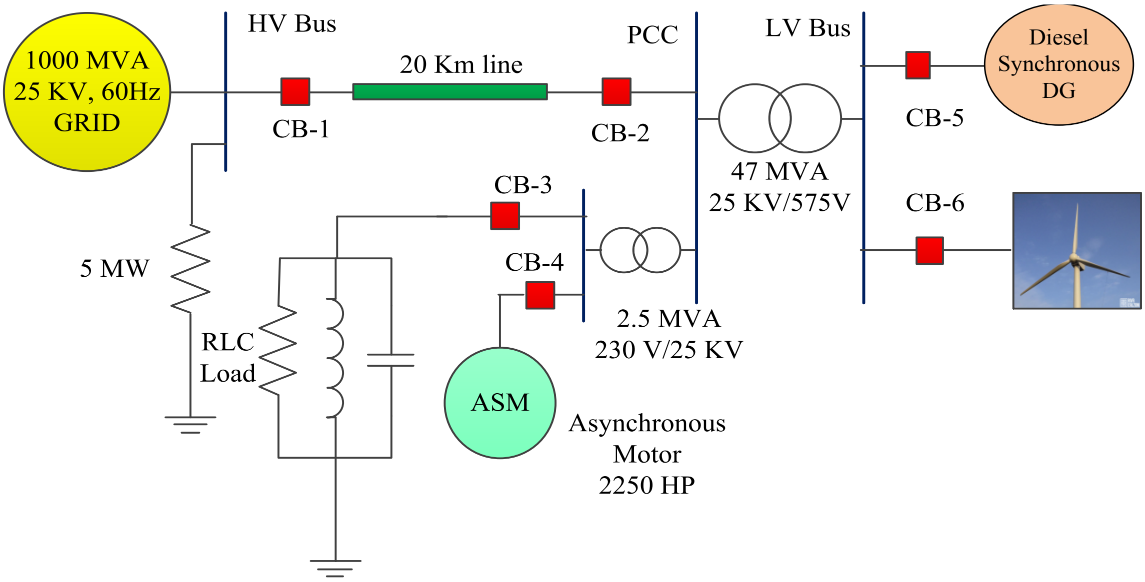

Fig. 2. Test system under study for performance evaluation of proposed method

The symmetrical components of currents are defined as (2)

$$\begin{bmatrix} i_{a0} \\ i_{a1} \\ i_{a2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (2)$$

Where V_{ao}, V_{a1} and V_{a2} are the zero sequence, positive sequence and negative sequence voltages. i_{a0}, i_{a1} and i_{a2} are the zero sequence, positive sequence and negative sequence current components. V_a, V_b, V_c and i_a, i_b, i_c are the three phase voltages and currents obtained at the PCC. The complex operator is given by (3-4)

$$\alpha = 1\angle 120^0 \text{ or } \quad \cos 120^0 + j \sin 120^0 \quad (3)$$

$$\text{and also } \alpha^2 + \alpha + 1 = 0 \quad (4)$$

The sequence components of voltages and currents can also be written as an equation (5) and (6). The equations (1- 6) indicates, the sequence components of voltages and currents before islanding.

$$\begin{aligned} v_{a1} &= \frac{1}{3}(v_a + \alpha v_b + \alpha^2 v_c) \\ v_{a2} &= \frac{1}{3}(v_a + \alpha^2 v_b + \alpha v_c) \\ v_{a0} &= \frac{1}{3}(v_a + v_b + v_c) \end{aligned} \quad (5)$$

$$\begin{aligned} i_{a1} &= \frac{1}{3}(i_a + \alpha i_b + \alpha^2 i_c) \\ i_{a2} &= \frac{1}{3}(i_a + \alpha^2 i_b + \alpha i_c) \\ i_{a0} &= \frac{1}{3}(i_a + i_b + i_c) \end{aligned} \quad (6)$$

The voltage at PCC before islanding is V_{PCC} and load impedance is Z_L, the load current is given by equation (7)

$$I_L = \frac{V_{PCC}}{Z_L} \quad (7)$$

However, after islanding the voltage at PCC is changed to V_{PCC} (1+ ΔV), now the change in current after islanding is given by

$$I_L^1 = \frac{V_{PCC}(1+\Delta V)}{Z_L} \quad (8)$$

The phase currents i_a, i_b, i_c and phase voltages V_a, V_b, V_c after islanding are changed as $i_a + \Delta i_a, i_b + \Delta i_b, i_c + \Delta i_c$ and $V_a + \Delta V_a, V_b + \Delta V_b, V_c + \Delta V_c$ respectively. Therefore, after islanding the PSV and PSC are changed as (9) and (10)

$$v_{a1}^1 = \frac{1}{3}\left[(v_a + \Delta v_a) + \alpha(v_b + \Delta v_b) + \alpha^2(v_c + \Delta v_c)\right] \quad (9)$$

$$i_{a1}^1 = \frac{1}{3}\left[(i_a + \Delta i_a) + \alpha(i_b + \Delta i_b) + \alpha^2(i_c + \Delta i_c)\right] \quad (10)$$

The equations (9) and (10) are derivated to get ROCOPSV and ROCOPSC. By observing the ROCOPSV and ROCOPSC the islanding is detected. In the grid connected mode these deviations are not present, but in islanding condition these changes are more and an islanding is detected with them.

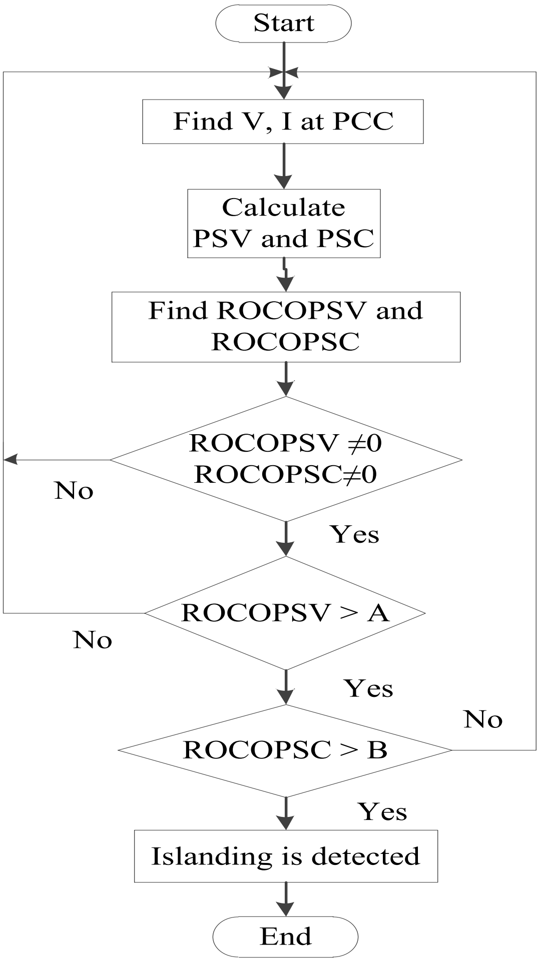

Fig. 3. Flow chart of the proposed islanding technique

3.2 *Flow chart of proposed islanding detection method*

In the integrated power system by using voltage and currents available at PCC, the phasor values of PSV and PSC are calculated. These values are continuously derivated to get ROCOPSV and ROCOPSC. The ROCOPSV and ROCOPSC are continuously compared with a predefined threshold values of A= 0.2 p.u/sec and B= 0.2 p.u/sec. If both the values ROCOPSV and ROCOPSC are more than these preceding values, then it is confirmed as islanding, otherwise it is considered as a non islanding condition. The step wise procedure is also depicted in Fig.3.

4. Results and Discussion

The realization of the recommended method is evaluated for the test system shown in Fig.2, for various cases of islanding and non islanding events such as capacitor switching, load switching etc. with various power mismatches along with grid connected operation.

4.1 *Grid connected mode*

The simulated results of voltages, currents, positve, negative and zero sequence components of voltages in steady state are shown in Fig.4. From these results it is found that negative sequence and zero sequence voltages are zero and only positive sequence components of voltages and currents are present in the grid connected mode of operation.

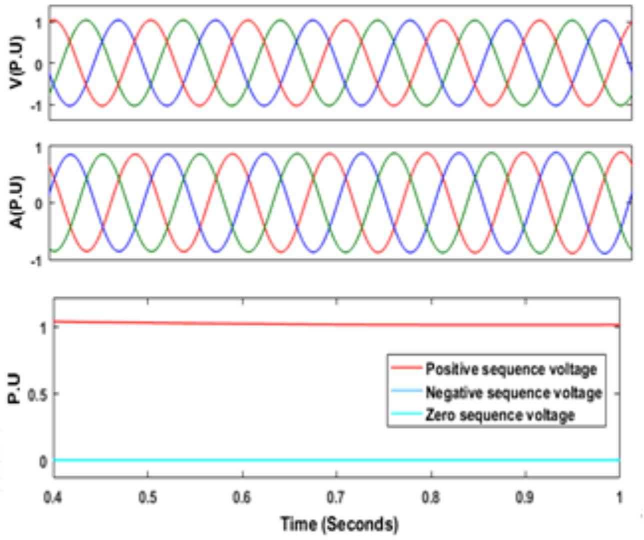

Fig.4. Voltages, currents, positive, negative and zero sequence voltages in grid connected operation

4.2 *Islanding with various power imbalances*

During small or zero power balanced condition, almost maximum passive methods are not detecting the islanding [49-51]. During the grid connected mode only the positive sequence component of voltages are present, negative and zero sequence components are zero. In the islanding and fault conditions, negative sequence components are present, if the fault is associated with ground zero sequence components will present.

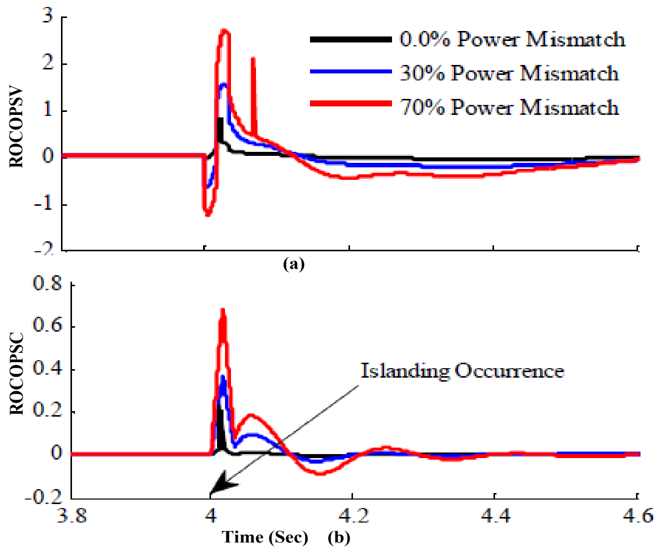

Fig. 5. Simulation results of (a) ROCOPSV and (b) ROCOPSC with various power imbalances

The ROCOPSV and ROCOPSC at PCC in different islanding modes are shown in Fig.5, at t= 4 the islanding is initiated by opening the C.B and shows that the changes in ROCOPSV and ROCOPSC are more than A= 0.2 p.u/sec and B= 0.2 p.u/sec threshold values, compared to zero in the grid connected mode. Hence islanding is detected with this method even at zero power imbalance condition.

4.3 *Performance for various short circuit faults*

The achievement of the proposed method is evaluated for various short circuit fault (SCF) like LG, LL, LLL etc. The ROCOPSV and ROCOPSC for various faults are shown in Fig.6.

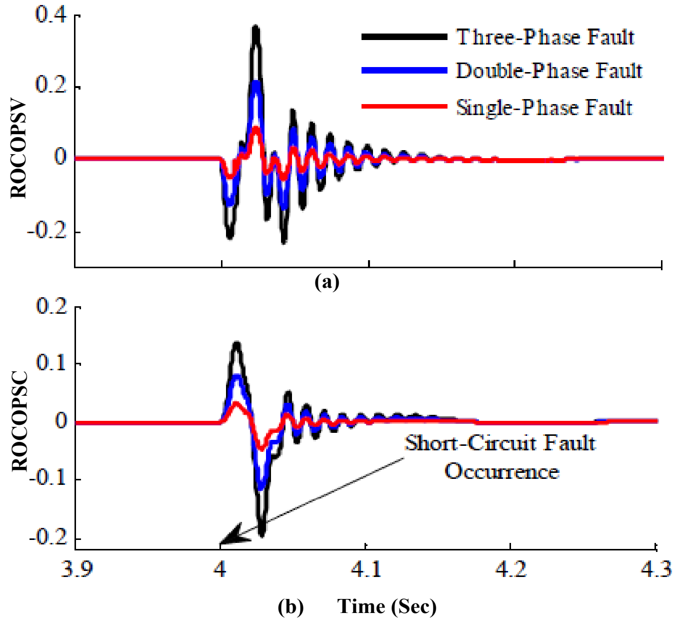

Fig. 6. Simulation results of (a) ROCOPSV and (b) ROCOPSC during various non islanding faults

These faults are switched at t= 4 sec and variations are observed. From the Fig.6 (a), it is clearly observed that, for three phase and double line faults the ROCOPSV is more than the setting value A= 0.2 p.u/sec, but for single line fault it is less than setting value. Fig.6 (b) shows the ROCOPSC is less than threshold value B= 0.2 p.u/sec for all faults. The method proposed in the reference [48] is failed to detect islanding for SCF. But the proposed method in this paper clearly separates the SCF from various islanding events.

4.4 *Different rating capacitor bank switching*

Generally capacitors are connected in parallel with the loads for improving power factor and compensating the voltage sags. When the capacitor is switched, the electrical passive parameters are changed and sometimes they may lead to wrong decisions on islanding events. Hence, to evaluate the performance of the proposed method, different size capacitors are switched at t=4 sec and results are recorded in Fig.7. The ROCOPSV shown in Fig.7 (a) is more than threshold value, but the ROCOPSC in Fig.7 (b) is less than threshold value of 0.02 p.u/sec. One is more and other is less, hence capacitor switching is non islanding event.

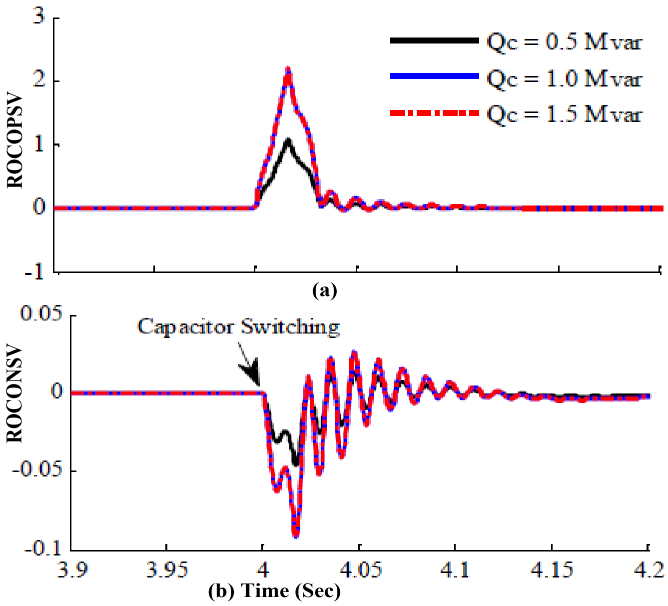

Fig. 7. Simulation results of (a) ROCOPSV and (b) ROCOPSC during various ranges of non islanding capacitor switching.

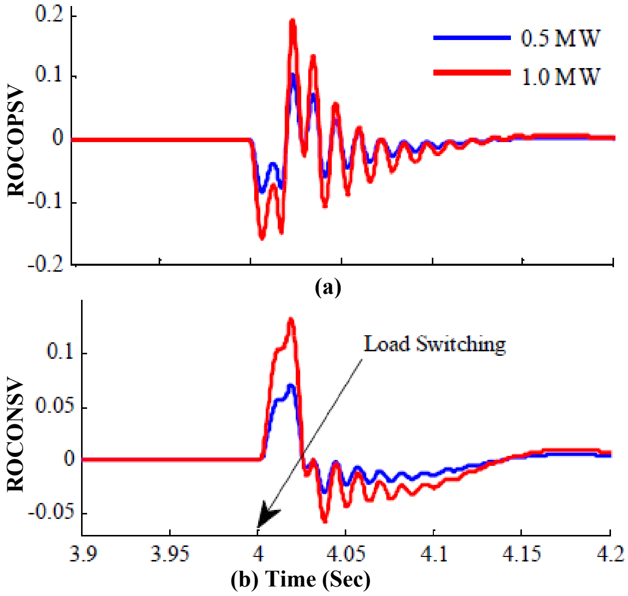

Fig. 8. Simulation results of (a) ROCOPSV and (b) ROCOPSC for load switching

4.5 *Proposed method for load switching*

The islanding detection is also affected by load switching because, the load switching leads to variations in passive parameters. The method proposed in [53] is taken a wrong decision on load switching events, it detects load switching non islanding events as islanding events and vice versa. To find the performance of the proposed method, various capacity loads are swithed at t = 4 sec, shown in Fig.8. It is observed from Fig. 8 (a) and Fig. 8 (b), the ROCOPSV and ROCOPSC are less than the threshold value 0.02 p.u/sec. Hence it is considered as a non islanding event. So this method is clearly separates load switching events as non islanding events from islanding events.

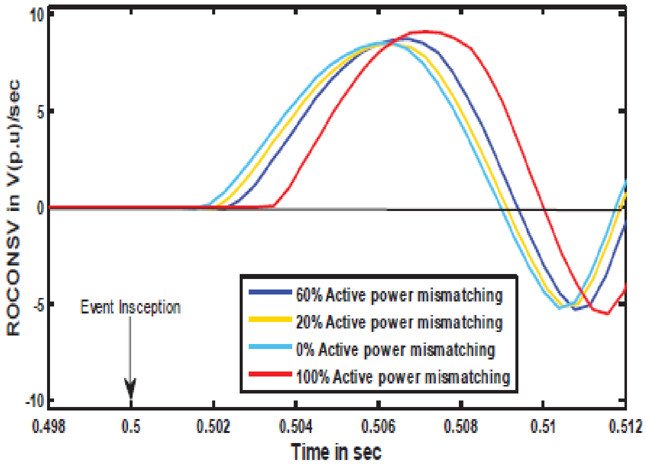

Fig.9. Rate of change of NSV at different active power imbalances

4.6 Comparison with existing methods

Table-II, shows the comparison of NDZ of different existing passive methods. Some methods taking more time for responding to islanding events and some methods are taking less time. The methods proposed in [48-53] are taking wrong decision on islanding events. It is observed from the results shown in Fig.5-8, the proposed method is clearly separating islanding and non islanding events within small time of 10 ms with zero NDZ. So many passive methods are not detecting islanding at zero power imbalance condition, but the proposed method can do it. The Fig.9, presents the islanding waveforms for negative sequence voltage detection technique. Which shows when islanding is caused at t= 5 ms, the islanding may be confirmed at t=0.506 ms. Hence this method can detect within 60 ms, but our method can detect within 10ms.

Table II: Comparison of different existing passive methods

Passive Islanding detection method	Detection time	NDZ
Voltage & current THD [32]	200 to 500 ms	Large with a large value of Q
OUV/ OUF [30], [66]	200 ms to 2s	Large
ROCOF [25], [47]	300 ms	Small
ROCOFOAP [31]	250 ms	Smaller than ROCOF
ROCOP [26]	400 ms	Smaller than OUV/OUF
Phase jump detection [35]	100-200 ms	Large
Voltage unbalance [17]	50 ms	Large
Switching frequency [36]	50 ms	None
Grid voltage sensor less [37]	45 ms	None
Fuzzy and S Transform [38]	20 ms	Very small
Discrete wavelet transforms [39]	20 ms	Very small
Wavelet packet transform [40]	Very small	None
Discrete wavelet transforms [41]	15 ms	None
Wavelet coefficients of transient signals [43]	30 ms	None
Wavelet [42], [65]	50 ms	Very small
Wavelet transforms & S-transform [44]	Very small	None
Voltage amplitude and frequency [45]	170 ms	Very small
Fast Gauss newton algorithm [46]	40 ms	Small
Forced hemaltz oscillator [57]	400	Small
Transient component based [56]	< one cycle	Very small
Auto correlation [58]	< Three cycles	Small
ANFIZ [59], [62]	Not reported (Less)	Negligible
Virtual impedance [60]	400 ms	Large
ROCOEVORP [61]	500 ms	Zero
ROCOPSV and ROCOPSC (Proposed method)	10 ms	Zero

5. Conclusion

In this paper a new hybrid passive method is proposed for islanding detection with ROCOPSV and ROCOPSC. The performance of this method is investigated on a test system with wind connected DFIG DG and diesel synchronous DG. Most of the passive techniques are failed to detect islanding at small power mismatch situations. This method detects islanding even at zero power imbalance condition. The comparison of existing methods are clearly shows that this method has negligible NDZ. Some methods wrongly detect islanding as non islanding and vice versa. The switching of capacitor bank, swithing of loads and SCF are differentiated as non islanding events with this method. The proposed method is clearly separating islanding and non islanding events within 10 ms with zero NDZ.

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