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Passive Islanding Detection Technique for Integrated Distributed Generation at Zero Power Balanced Islanding

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Abstract: Renewable power generation systems have more advantages in the integrated power system compared to the generation due to fossil fuels because of their advantages like reliability and power quality. One of the important problems due to such renewable distributed generation (DG) system is an unintentional islanding. Islanding is caused if DG supplies power to load after disconnecting from the grid. As per the DG interconnection standards, it is required to detect the islanding within two seconds after islanding with the equipments connected to it. In this paper a new passive islanding detection method is presented for wind DG integrated power system with 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 are carried on MATLAB shows the performance of the proposed method for various islanding and non islanding events with different power imbalances. The results conclude that, this method can detect islanding even at balanced islanding with zero non detection zone (NDZ).

Keywords: Islanding detection, Integrated distributed generation, ROCOPSV, Balanced islanding, NDZ.

1. Introduction

Nowadays to meet the global energy consumption demand, it is better to look towards renewable power generation. 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), intentional opening of CB for maintenance, human errors and an act of nature [3]. The basic grid interfacing rules listed in the Table 1, needs that it is necessary to disconnect the DG source within 2 seconds after islanding, because if the island load is more or less, then it leads to variations in the voltage, frequency, current, total harmonic distortion (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

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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 their changes are 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], ROCOAP combination with ROCORP [34]. These methods will reduce the NDZ to less compare to single parameter passive techniques. But most of the passive method fails to detect islanding at low or zero power imbalance conditions.

In this paper a new 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. This result 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 1 - Islanding detection time, frequency and voltage ranges of various standards

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

2. Test System Under Study

The principle 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 voltage and currents are input to the proposed detection process. 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 wood word 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 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.

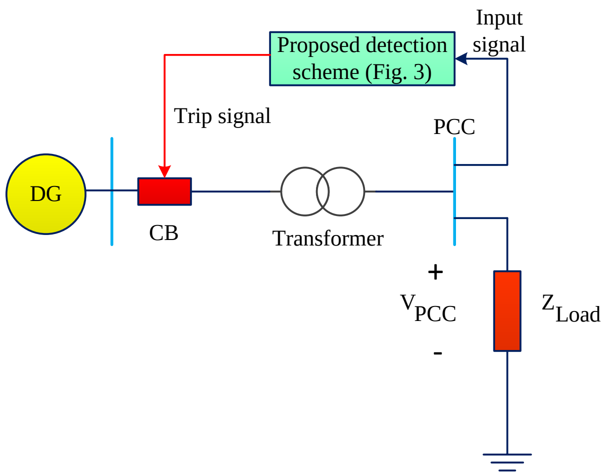

Fig. 1- Principle of islanding detection scheme

3. Test System Under Study

3.1 Mathematical modelling of proposed method

The balanced voltages and currents at PCC are equal in magnitude and 120^0 apart from each other. After islanding the voltages and currents are unbalanced. 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. The negative sequence components present during the islanding operation. The positive sequence components will present in all modes. The symmetrical components of voltages at PCC are defined as (1)

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

The symmetrical components of currents at PCC are written as tion (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_{a0}, 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 at obtaining at the PCC. The complex operator is given by (3-4).

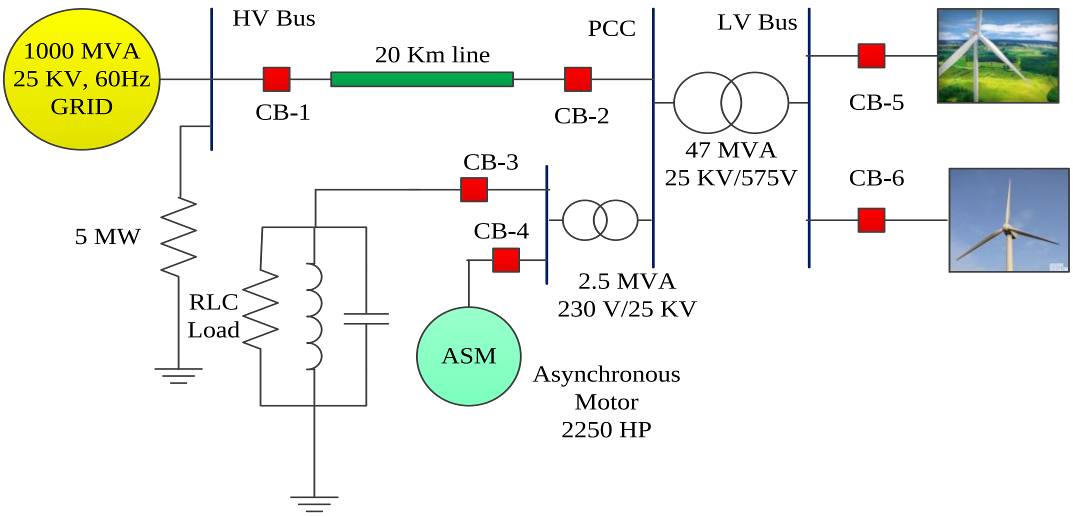

Fig. 2 - Test system under study for performance evaluation of proposed method

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

$$\text{and also } \alpha^{2} + \alpha + 1 = 0 \tag{4}$$

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.

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

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

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

$$I_L = \frac{V_{PCC}}{Z_L} \tag{7}$$

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

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

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 this deviation are not present, but in islanding condition these changes are more and an islanding is detected.

3.2 Flow chart of Proposed Islanding Detection Technique

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 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 threshold 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.

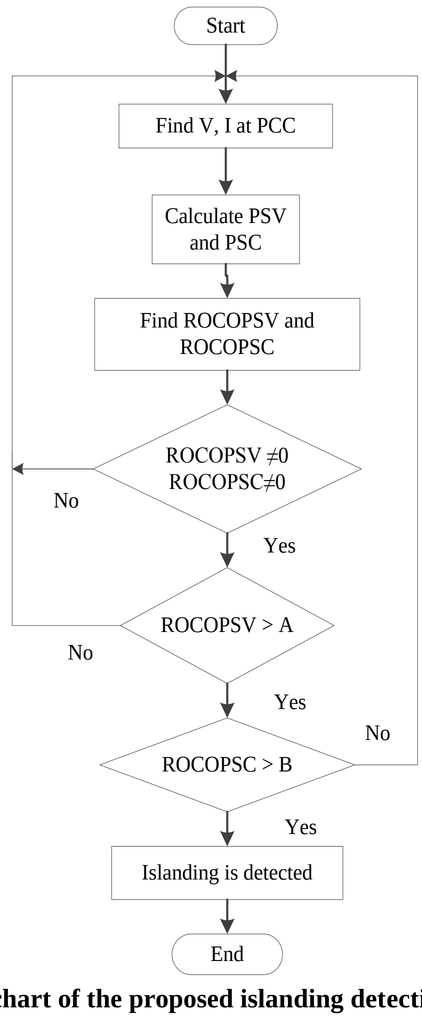

Fig. 3 - Flow chart of the proposed islanding detection scheme

4. Results and Discussion

The performance of the proposed method is evaluated on the test system shown in Fig.2, for various cases of islanding and non islanding events with various power mismatches.

4.1 Grid Connected Mode

The simulated results of voltage, current, active power and reactive power under steady state are shown in Fig.4. The DC link voltage, frequency is shown in Fig.5. The positive, negative and zero sequence voltages in the grid connected operation are shown in Fig.6. 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.

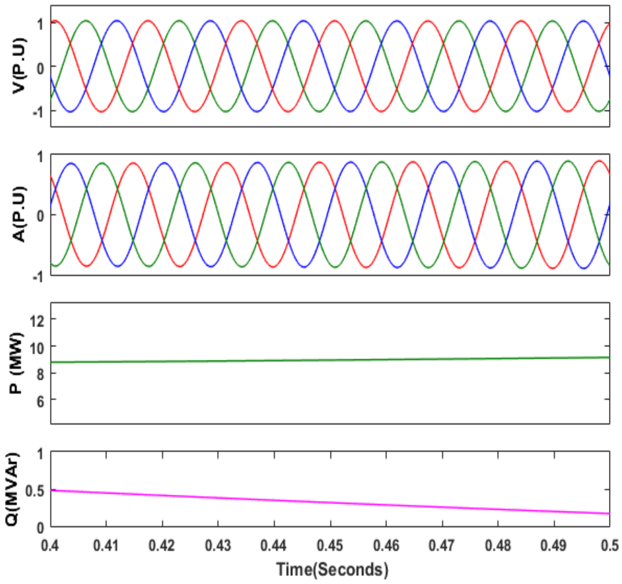

Fig.4 - Voltages, currents, active power and reactive power of grid connected operation

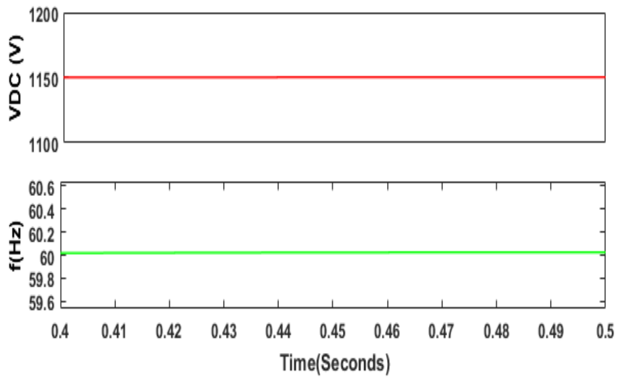

Fig.5 DC link voltage and frequency of grid connected operation

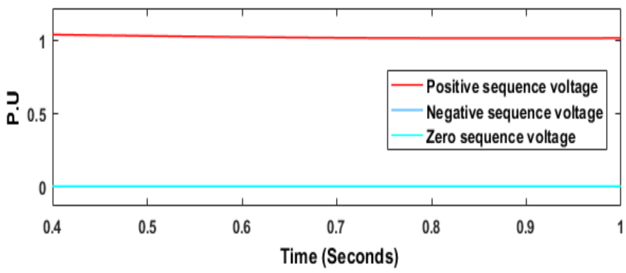

Fig.6 - Positive, negative and zero sequence voltages in grid connected operation

4.2 Islanding with Various Power Imbalances

Most of the passive islanding detection methods are failing to detect islanding at zero or small power imbalance condition of islanding [49-51]. During the grid connected mode only the positive sequence component of voltages is 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 also present.

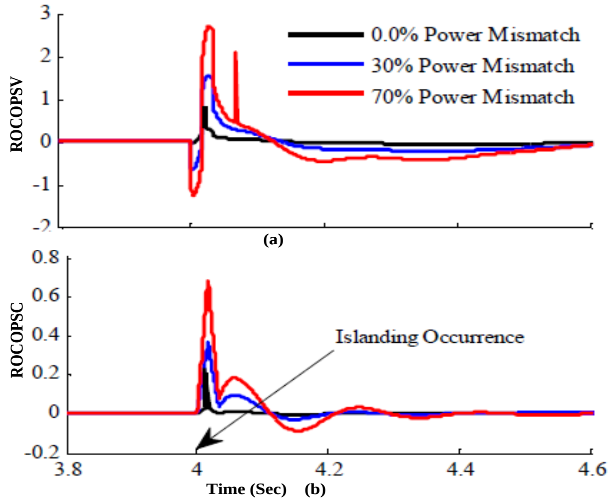

Fig. 7 - Simulation results of (a) ROCOPSV and (b) ROCOPSC with various power imbalances

The ROCOPSV and ROCOPSC at PCC in different islanding modes are shown in Fig.7, 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 Islanding with Various Power Imbalances

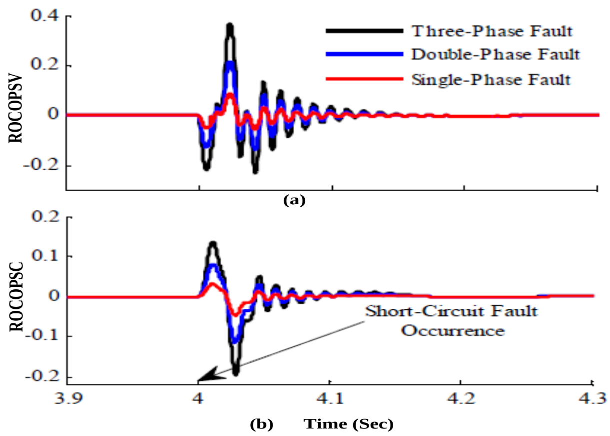

Fig. 8 - Simulation results of (a) ROCOPSV and (b) ROCOPSC during various non islanding faults

The performance 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.8. These faults are switched at t= 4 sec and variations are observed. From the Fig.8 (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.8 (b) shows the ROCOPSC is less than the threshold value B= 0.2 P.u/Sec for all faults. The method proposed in the reference [48] is failing to detect islanding for SCF. But the proposed method in this paper clearly separates the SCF from various islanding events.

4.4 Islanding with Various Power Imbalances

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.9. The ROCOPSV shown in Fig.9 (a) is more than the threshold value, but the ROCOPSC in Fig.9 (b) is less than the threshold value of 0.02 P.u/ Sec. One is more than threshold value and another is less, hence the switching of capacitor is considered as non islanding events.

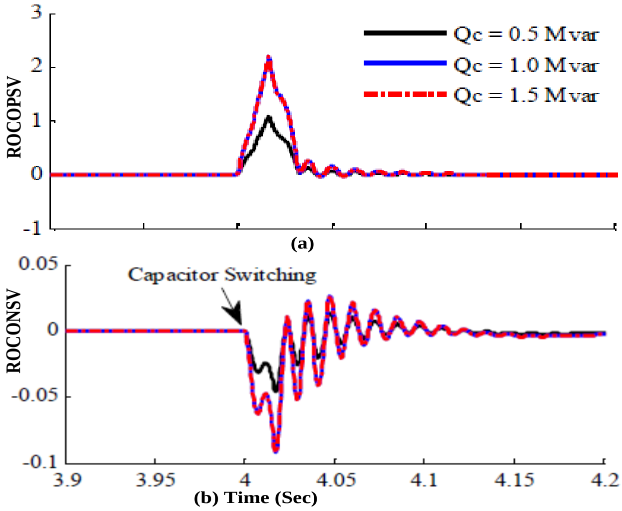

Fig. 9 - Simulation results of (a) ROCOPSV and (b) ROCOPSC during various ranges of non islanding capacitor switching.

4.5 Islanding with Various Power Imbalances

When the induction motors are switched on or off the electrical parameters are changed and leads to wrong decision on islanding detection. To find the performance of the proposed method, two different large size induction motors are switched at t= 4 Sec. The simulation results for induction motor switching are shown in Fig.10. The ROCOPSV shown in Fig. 10 (a), the changes are less than the pre threshold value, but the ROCOPSC shown in Fig.10 (b) changes are more than the threshold value of 0.02 P.u/ sec. The large current drawn by induction motor may lead to wrong decision, but the decision is corrected by ROCOPSV changes. The method proposed in [52] wrongly detects induction motor starting as islanding, but the proposed method in this paper correctly classified induction motor switching as a non islanding event.

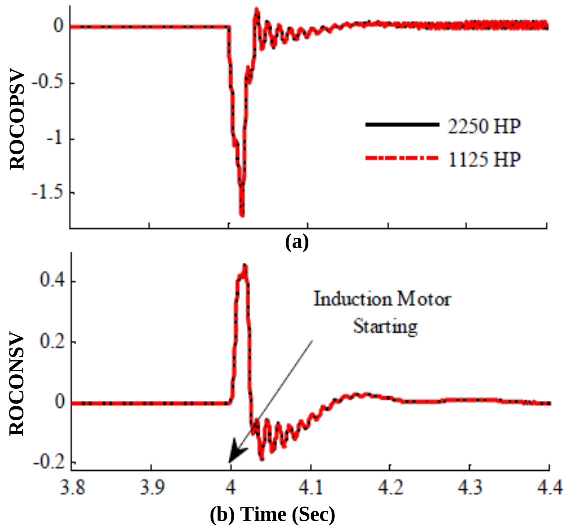

Fig. 10 - Simulation results of (a) ROCOPSV and (b) ROCOPSC during induction motor starting with different capacity

4.6 Islanding with Various Power Imbalances

The islanding detection is also affected by load switching. The method proposed in [53] is taken a wrong decision on load switching events. To find the performance of the proposed method, various capacity loads are switched at t = 4 sec shown in Fig.11. It is observed from Fig. 11 (a) and Fig. 11 (b), the ROCOPSV and ROCOPSC are less than the threshold value 0.02 P.u/sec. Hence this method clearly separates load switching events as non islanding events from islanding events.

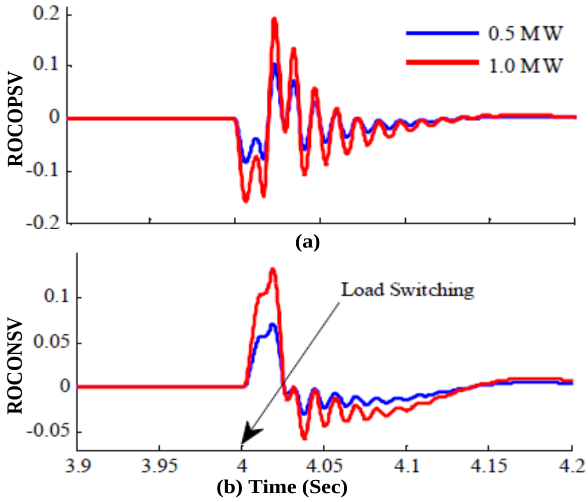

Fig. 11 - Simulation results of (a) ROCOPSV and (b) ROCOPSC for load switching

4.7 Islanding with Various Power Imbalances

Most of the passive methods presented in Table 2, has large and small NDZ. Some methods take 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.7-11, the proposed method clearly separates 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.

Table 2 - 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]	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]	50 ms	Very small, Nearly zero
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
ROCOPSV and ROCOPSC (Proposed method)	10 ms	Zero

5. Conclusion

All a 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 failing to detect islanding at small power mismatch situations. This method detects islanding even at zero power imbalance condition. Some methods wrongly detect islanding as non islanding and vice versa. The proposed method clearly separates islanding and non islanding events within 10 ms with zero NDZ.

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