Islanding Detection in Microgrid Based on Impedance Insertion

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ABSTRACT

In the present day there is anincreasing demand of the energy. To meet this demand renewable technology e.g. solar PV, wind, tidal, fuel cell etc. is coming into the picture and we are using this technology with the grid connected mode to increase the reliability and efficiency. As we are using this technology in the grid connected mode there are several parameter to be considered for secure operation of this microgrid. One of this is islanding of the renewable sources to the main grid. This paper present a novel islanding detection based on the impedance insertion. This method uses the concept of current measurement. This used method has several advantages over the other method and small Non Detection Zone (NDZ).

Keywords- Microgrid, NDZ, Islanding, Current measurement, Impedance insertion.

I. INTRODUCTION

As we know at present there is very high demand of the electricity. Besides very hard effort there is no access to electricity to every person of the nation. Our per capita consumption is very less when compared with the other countries per capita consumption. Also if we use the conventional method to increase the installing capacity of the power there will be increased concern over the environment issue. Thus we required to meet the demand without these drawbacks. So at present we are working on the high penetration of the renewable technologies in the power system. Thus this sources are increasing the reliability and the continuity of the power supply to the consumer as we are using this sources with the connection to the grid. This connection of the renewable resources to the grid is called the microgrid. These renewable sources are environment friendly and does not cause any harmful effect to the environment [1], [2]. As we are using this renewable sources in the grid connecting mode there are several technological issue to be considered forfrequency, voltage, power angle, power flow etc.

Whenever power system is subjected to any contingencies it becomes very important to operate the proper control scheme to maintain the system parameter within the limit. Thus detection of these contingencies phenomenon becomes important to operate the control logics within very short period of time. As we have discussed that we are using the renewable resources connected to the main grid so there may be possibility that any contingencies may occur in this microgrid so in this case we are required to isolate the faulty part of the system whether it is grid side or the renewable sources side. This isolating phenomenon is called the islanding. We are required to detect this isolating phenomenon to operate the proper control logic to maintain the system parameter within the limit [3]. There are several methods have been discussed so far to detect this islanding in power system which is categorized as active, passive and remote method. Active method is based on the inserting perturbation in the system while passive method direct measure the local parameter and compare it to

the set threshold to detect the islanding. Remote method is based on the detection of the states of the breakers to detect the islanding in the power system. The remote method has several advantages over the other method e.g. it has no issue of the NDZ (Non-Detection Zone), no effect over the power quality as it does not insert the perturbation in the system to detect the islanding. Overall this method is very much effective over the other two counterpart but this method is costly to use for the small system [4].

II. PROPOSED METHOD

Basic proposed islanding detection circuit is shown in the below figure. At the one side the AC source represent the supply from the grid and other side the inverter output shows the DC to AC conversion from distributed sources like solar, wind etc. In case any fault occur toward the grid side than circuit breaker connected to the main grid opens in that condition main grid is disconnected from the microgrid and supply to the load only by the microgrid DERs. Prior to the circuit breaker opening the current in the both ammeter remains different but after the breaker opening the current in the inserted resistance branch becomes equal to the ammeter 1 i.e. both the current measured by the ammeter becomes equal [5].
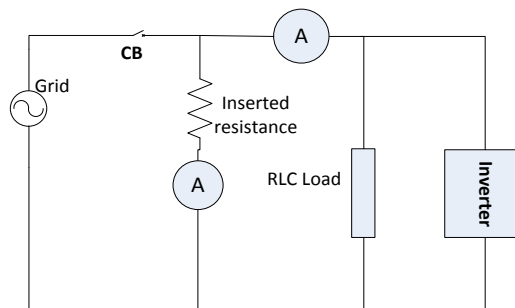

Fig. 1 proposed islanding detection circuitry

Thus this method of the islanding detection is a passive method based on the current measurement and its comparison in case of the islanding. The proposed method has the following advantages [5]:

* The impedance every time remain connected to the system, so other auxiliary like extra switches and other equipment are not necessary thus time delays are avoided. Thus this proposed islanding Detection Method is simple, fast and accurate.

* The value of the inserted impedance are very large, so energy losses remains very less due to very low current flowing in the inserted resistance.

* There are not any unwanted distortions and perturbations injected into the system or any equipment sensitive to perturbations.

* The current measured by the high value of resistance acts as an indicator of the operating status of the microgrid whether it is connected or disconnected, thus this method is free from any communication overheads.

* This method does not disturb the power quality of the remaining system and its effectiveness remain as it is, whatever be the mode in which inverter is operating, i.e. current Control or voltage Control mode (CC or VC).

* It does not depend from operation of number of inverters in the MG and it gives satisfactory NDZ.

This paper develops a model for the DC link with the help of the solar and wind power which is synchronized with the grid and islanding detection circuitry is used to detect the islanding condition in case of the fault toward the grid side. The simulation studied is performed on the MATLAB/ Simulink R2013a software.

III.SYSTEM DESCRIPTION

The system consist of the model of the solar panel and the wind turbine to form the DC link of the. To simulate the solar panel model, the basic equation of the single diode model of the solar panel is used. The following equivalent circuit of the solar panel is used to simulate the characteristics of the solar panel.
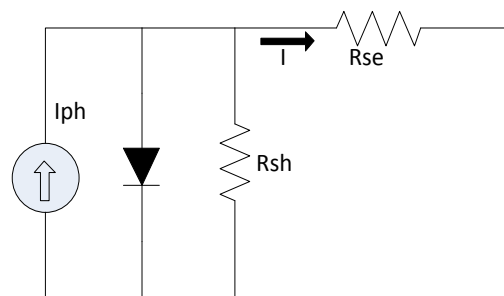

Fig. 2 single diode model of the solar panel [6]

In the figure shown below the general solar model consist of the photo current, a diode, a parallel resistance to express the leakage current and a series resistance shows the internal resistance to the current flow. The description of the basic equation of the modelling is shown below which satisfy all the characteristics of the solar panel [6] [7].

The solar panel V-I characteristic is given by the following equation [8]:

$$I = I_{PH} - I_S\left[\exp\left(\frac{q(V + IR_S)}{KT_C A}\right) - 1\right] - \frac{(V + IR_S)}{R_{SH}} \dots\dots\dots\dots..(1)$$

Where I_{PH} = photocurrent of the solar cell, I_S= saturation current of the solar cell, K= voltazman constant= 1.68×10^{-23} J/K, q=1.6×10^{-19} C, A= ideality factor of the cell, Rs= Series resistance, R_{SH}= shunt resistance, Tc= cell working temperature.

The photo current of the solar cell mainly depends on the insolation and the cell's working temperature is given by:

$$I_{PH} = [I_{SC} + K_I(T_C - T_{Ref})]S \dots\dots\dots\dots.(2)$$

Where S= solar cell's insolation in KW/m^2, K_I= cell's short circuit current temperature coefficient, T_{Ref}= cell's reference temperature, I_{SC}= cell's short circuit current at 25˚C and 1 kW/m^2 insolation

On the other hand cell's saturation current varies as the cell's working temperature which is given by:

$$I_S = I_{RS}\left(\frac{T_C}{T_{Ref}}\right)^3 \exp\left[qE_G(1/T_{Ref} - 1/T_C)KA\right] \dots\dots\dots\dots\dots(3)$$

I_{RS}= cell's reverse saturation current at the reference temperature and the solar irradiance, Eg= band gap energy of the material used in the solar cell.

For an ideal PV cell, there is no series loss and there is no leakage current that means Rs=0, Rsh=∞, so V-I characteristic of the cell becomes

$$I = I_{PH} - I_S\left[\exp\left(\frac{qV}{KT_CA}\right) - 1\right] \dots\dots\dots..(4)$$

Since a general PV cell generates less than 2W at 0.5V approximately, the cells should be connected in series-parallel configuration on a big panel to produce high power. A PV array is a set of several PV modules which are electrically connected in form of series and parallel circuits to produce the required amount of current and voltage. If Np= number of cells in parallel & Ns= number of cells in series, then the equation of voltage and of the PV array becomes,

$$I = N_P I_{PH} - N_P I_S\left[\exp\left(\frac{q\left(V/N_S + \frac{IR_S}{N_P}\right)}{KT_CA}\right) - 1\right] - \frac{\frac{N_P V}{N_S} + I R_S}{R_{SH}} \dots\dots\dots\dots\dots(5)$$

Using the above equations, the solar panel model is built in the Matlab/Simulink software which is used to simulate the generalized characteristics of the solar PV system as like as real physical panel. As we know that there will be maximum efficiency we will get from the solar panel if we operate this at the maximum power point so we required to operate the solar panel with the maximum power point technique [10]. So we are using the well-known perturb and observe method for the MPPT. MPPT output pulse is used to generate the switching pulse for the boost converter switching device [11].

As we know that the output voltage from the solar panel is very less so we required to boost the solar panel voltage with the help of the boost converter. The basic model with the design equation of the boost converter is shown below [12]:
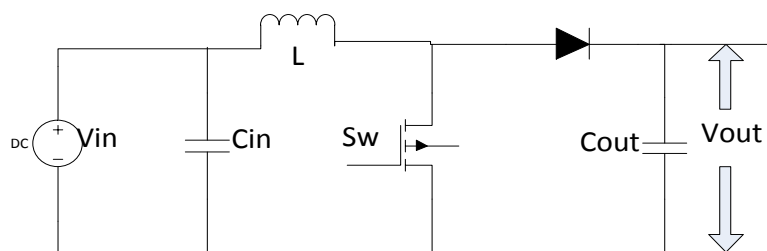

Fig. 3 basic circuit of the boost converter [13]

The design formula used for the boost converter is design is given below [13]:

Duty cycle of the switching pulse is given by,

$$D = 1 - \frac{V_{in}}{V_{out}} \dots\dots\dots\dots..(6)$$

WhereV_{in} is the input DC voltage to the boost converter and V_{out} is the required output voltage of the boost converter.

$$\Delta I_l = 1 \ to \ 5\% \ of \ I_{lmax} \dots\dots\dots.(7)$$

Where ΔI_l is the inductor current ripple and I_{lmax} is the maximum inductor current of the boost converter.

$$L = \frac{V_{in}(V_{out} - V_{in})}{\Delta I_l \times f_s \times V_{out}} \dots\dots\dots\dots\dots (8)$$

Where L is the inductor value calculations whichshould be inserted in the power stage of the boost converter and f_s is the switching frequency of the semiconductor device used to make the boost converter.

Value for the output side capacitor which is used in the boost converter to increase voltage is given by the following formula:

$$C_{out} = \frac{I_{out(max)} \times D}{f_s \times \Delta V_{out}} \dots\dots\dots\dots\dots\dots (9)$$

$I_{out(max)}$ is the maximum output current necessary in the application and ΔV_{out} is the desired output voltage ripple in the output stage of the boost converter.

These are the design parameter which is used to calculate the inductor and the capacitor value selection in the boost converter power stage. The input capacitor value is calculated by the provided datasheet of the design of the boost converter power stage. The solar PV we have taken to give the 500W output power. There are following value is taken to design the inductor and capacitor of the boost converter:

Voc= 66 V, Vm= 54.2 V, Isc= 25.44 A, Im= 23.25 A and fs= 5 KHz

Following values we have obtained for the design of the boost converter:

D= 0.9

L= 0.1 H

C= 0.02 F

For calculating the values of the filter we have taken1% ripple in the inductor current. The figure 4 shows the Simulink model for the solar panel used in our system.This panel consist of the MPPT algorithm based on the perturb and observe method. The switching pulse generated from the MPPT is used to switch the semiconductor device used in the boost converter to track the maximum power for the system. The design is based on the values which we have found from the above discussed parameter. The boost converter with the required parameter i.e. duty cycle, inductor and capacitor is employed to boost the voltage from the solar panel.
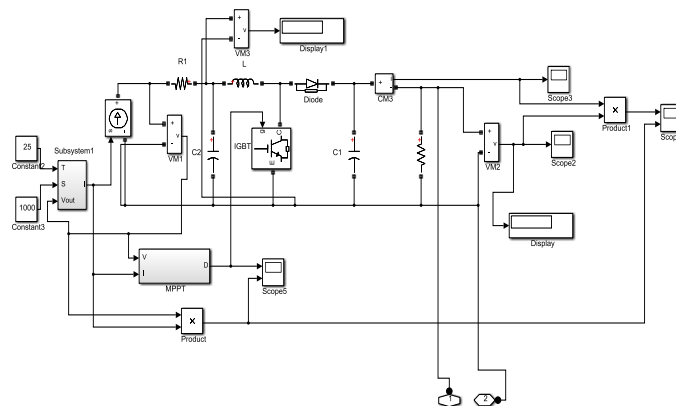

Fig. 4 simulink model of the solar panel

We have used the Permanent Magnet Synchronous Generator (PMSG) to generate the electricity from the wind power. The wind turbine rotates the PMSG to generate the electricity from the wind power [15]. But the output voltage from the wind generator is AC in nature which required to be converted into DC for connecting it to the DC link therefore the output AC voltage of the wind generator is converted to DC with the help of VSC. The specifications of the wind turbine used in our model is given below:

Table 1: Wind turbine specifications

Parameters	Values
Nominal mechanical output power	1.5 KW
Base wind speed	12 m/s
Pitch angle	45
Power factor	0.9

The output power from the wind turbine is used to rotate the PMSG generator which generate the electricity at required frequency and voltage. The generated voltage is AC in nature so we use the VSC to convert this to DC at 420V. Now the DC from the dc link is converted to AC by using the SPWM inverter for synchronizing with the grid voltage magnitude and frequency. There are following parameter we have taken of the connected generator toward the grid side:

Table 2: Parameter for connected generator

Parameters	Values
3- phase short circuit level at base voltage	5MVA
Base voltage (line to line RMS)	400 V
X/R ratio	7
Generator type	Swing
Internal connection	Y-g
Phase angle of phase A	0 degree
Frequency	50 Hz

The output of this generator is synchronized with the SPWM output. The output from the SPWM inverter contains the harmonics so we required to overcome this harmonics using the filter so for this LC filter is used. The value for the LC filter is L= 4.8 mH and C =5.7μF which is calculated using the filter design parameter for the inverter. The SPWM inverter operation is based on the comparison in which carrier wave is compared with the reference signal. We have used three sine wave which has phase shift of 120 degree compared with the 10000 Hz triangular wave to generate the switching pulse for the semiconductor device of the inverter. The Simulink model for the SPWM inverter used is shown below in figure 5:
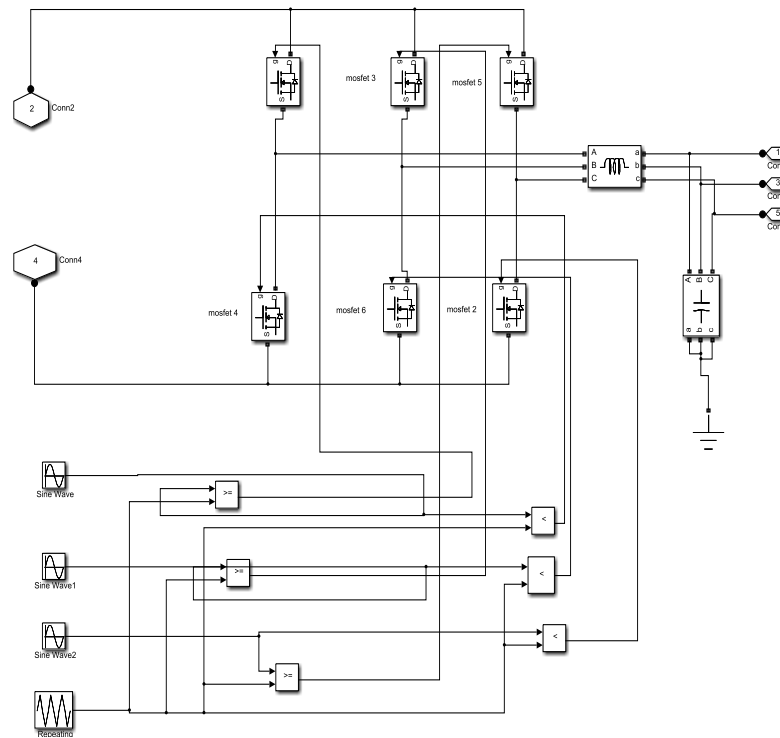
Fig. 5 simulink model for the SPWM inverter

The Simulink model based on the islanding detection circuitry is shown in the figure 1 which is supplied by the inverter side and from the generator side is shown below. In which the value of the inserted resistance is 735Ω and the values of the RLC load is R= 3.28KΩ, L= 10.45 H and C= 0.968µF. the fault is applied on the phase A toward the grid side at t= 2 sec. The RMS current measurement is also done toward the inverter side and in the inserted resistance for comparison of the current to detect the islanding. This is done by inserting the RMS current measurement block of the Simulink in all the three phases at the inverter side of the grid and in the inserted resistance for islanding detection. Both the breaker toward the grid side is inserted to isolate the fault from the healthy microgrid side and isolate the generator from supplying the fault. This simulation model has been made on the MATLAB Simulink software R2013a to detect the islanding.
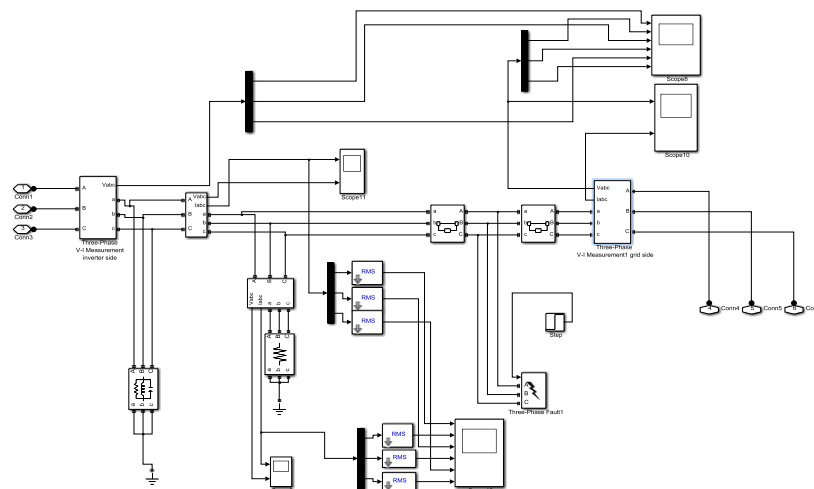

Fig. 6 islanding detection circuitry in case of phase 'A' fault toward grid side

Now all the system are combined to show the islanding phenomenon in the system and its detection through the proposed method.
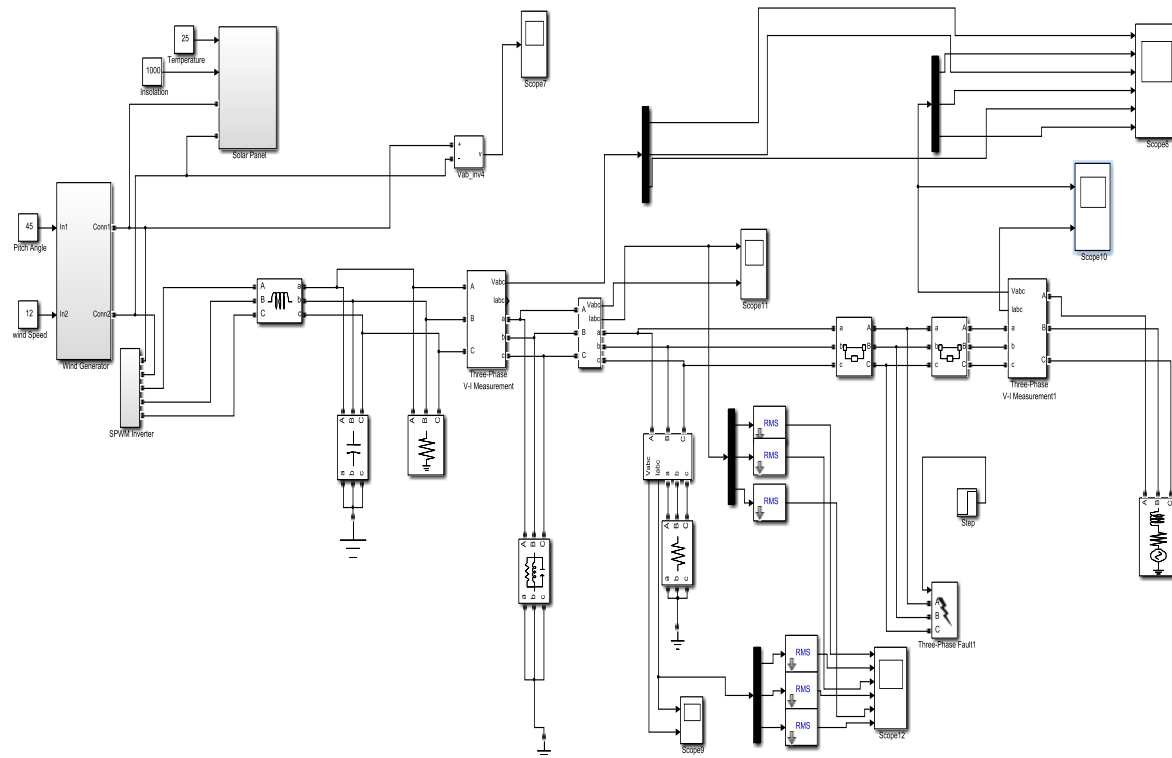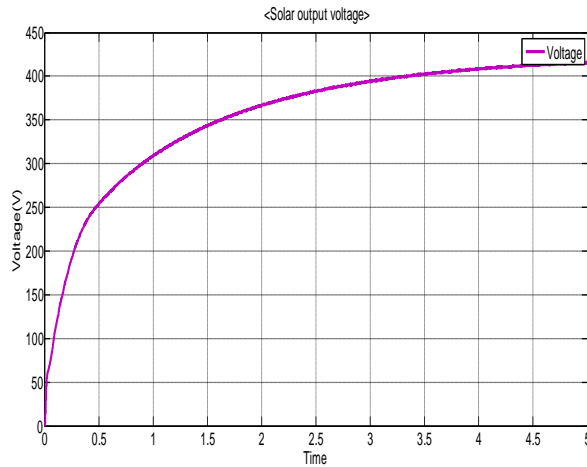

Fig. 7 simulink model for the islanding detection in the proposed microgrid
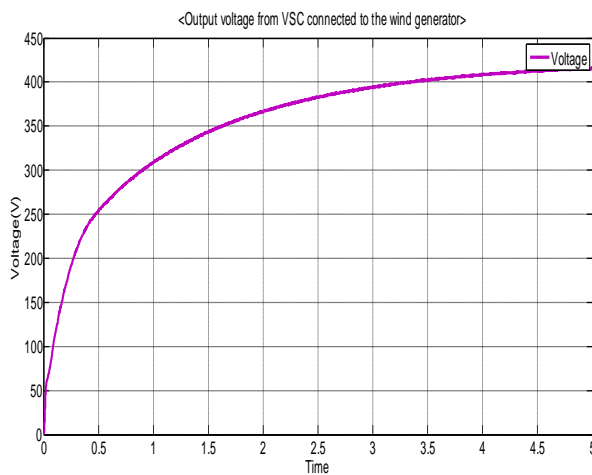
In the above model the subsystem consist of the solar panel model, wind generator model and the SPWM inverter as discussed is the above sections. The output of the solar is connected to the DC link and the output from the wind turbine is connected first to the VSC which is converted to the DC then connected to the DC link. Now the DC voltage is converter to the AC of proper frequency and voltage with the help of the SPWM inverter for synchronization to the grid. The islanding detection circuitry is connected between the grid side and the inverter side to detect the islanding phenomenon in the system.
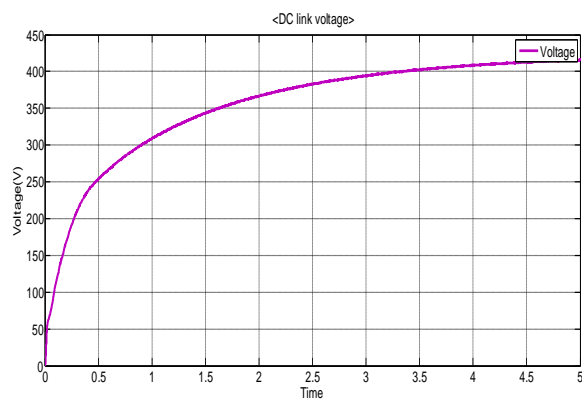
IV. SIMULATION RESULTS

As we know that the output voltage from the solar is DC in nature and the wind generator output is connected to the VSC to convert it to DC because the output from the wind turbine connected permanent magnet synchronous generator is AC in nature but we required to form the DC link so we converted it to the DC of proper magnitude which will be same as the output voltage of solar. Now both the voltage of same magnitude is connected to the DC link. After connecting it to the DC link this voltage is again converted to AC of proper magnitude and phase for synchronization to the grid with the help of the SPWM inverter. The islanding detection circuitry to detect the islanding is connected between the SPWM output and the grid. This is explained ahead in the figure 9. The magnitude of the output voltage from the solar panel and the VSC connected to the wind turbine is 420 V which is DC in nature. The output voltage from solar is shown in figure 8 (a) and output voltage from VSC connected to wind generator which is DC in nature and the DC link voltage is shown in the below wave forms in figure 8 (b) and 8 (c):

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(a)

(b)

(c)

Fig. 8 (a) output voltage from the solar panel (b) output voltage from the VSC connected to wind generator (c) DC link voltage

The above DC link voltage is connected to the SPWM inverter which convert it to proper frequency and magnitude to synchronize with the grid. The output synchronized voltage of the SPWM inverter and the grid is shown in the below figure:
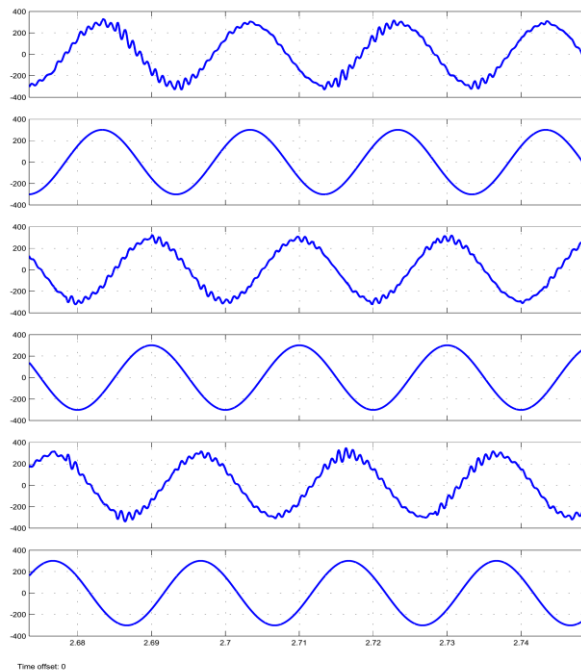
Fig.9 output voltage waveform at the inverter side and connected grid

In the above figure which contains the harmonics is the output waveform at the inverter side and the waveform which is pure sinusoidal is from grid side. Both the waveform is synchronized.

Now at t= 2 sec, a line to ground fault occur in the phase 'A' at the grid side so the current in the phase 'A' overshoot to its normal value at t=2 sec. This phenomenon has been shown in the figure 10 in which the current waveform of phase 'A' i.e. Ia is increased beyond its normal value at time t= 2 sec. but the current in the other two phases remain in the normal limit. At t= 3 sec grid side breaker is operated thus current in phase 'B' and phase 'C' becomes zero but the fault is supplied by the generator as generator side breaker is not operated thus fault current remain as it is as the previous one. To isolate the fault in the phase 'A' of the grid side at t= 4 sec the generator side breaker is operated and the fault current becomes zero at t= 4 sec. The current and the voltage waveform toward the grid side in high resolution is shown in the below figure:
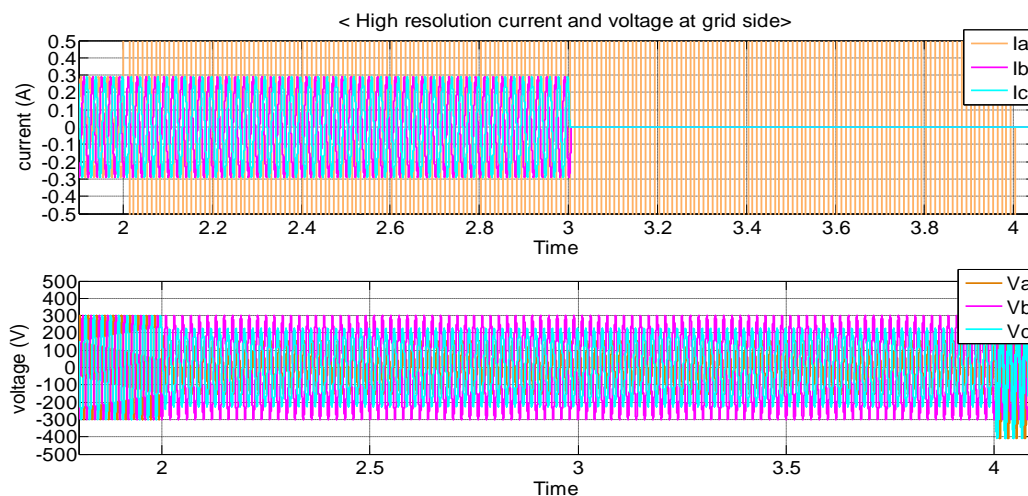

Fig. 10 high resolution current and voltage waveform at the grid side

Before t= 3 second as both microgrid as well as grid connected in the system, the inverter side current will be different from the current in the inserted resistance. This shows that there is no islanding occur in the system but after t= 3 sec as the grid is isolated from the microgrid because of the breaker operation, the current in the inserted resistance becomes equal to the current toward the inverter side. This shows the islanding phenomenon in the system. The waveform for the islanding phenomenon is shown in the figure 11. Thus this is a passive method based on the current comparison of current in inserted resistance and inverter side.Thewaveform shown in figure 11 (a) is the current and voltage in the inserted resistance and the waveform in the figure 11 (b)is the current and voltage toward the inverter side in the high resolution.
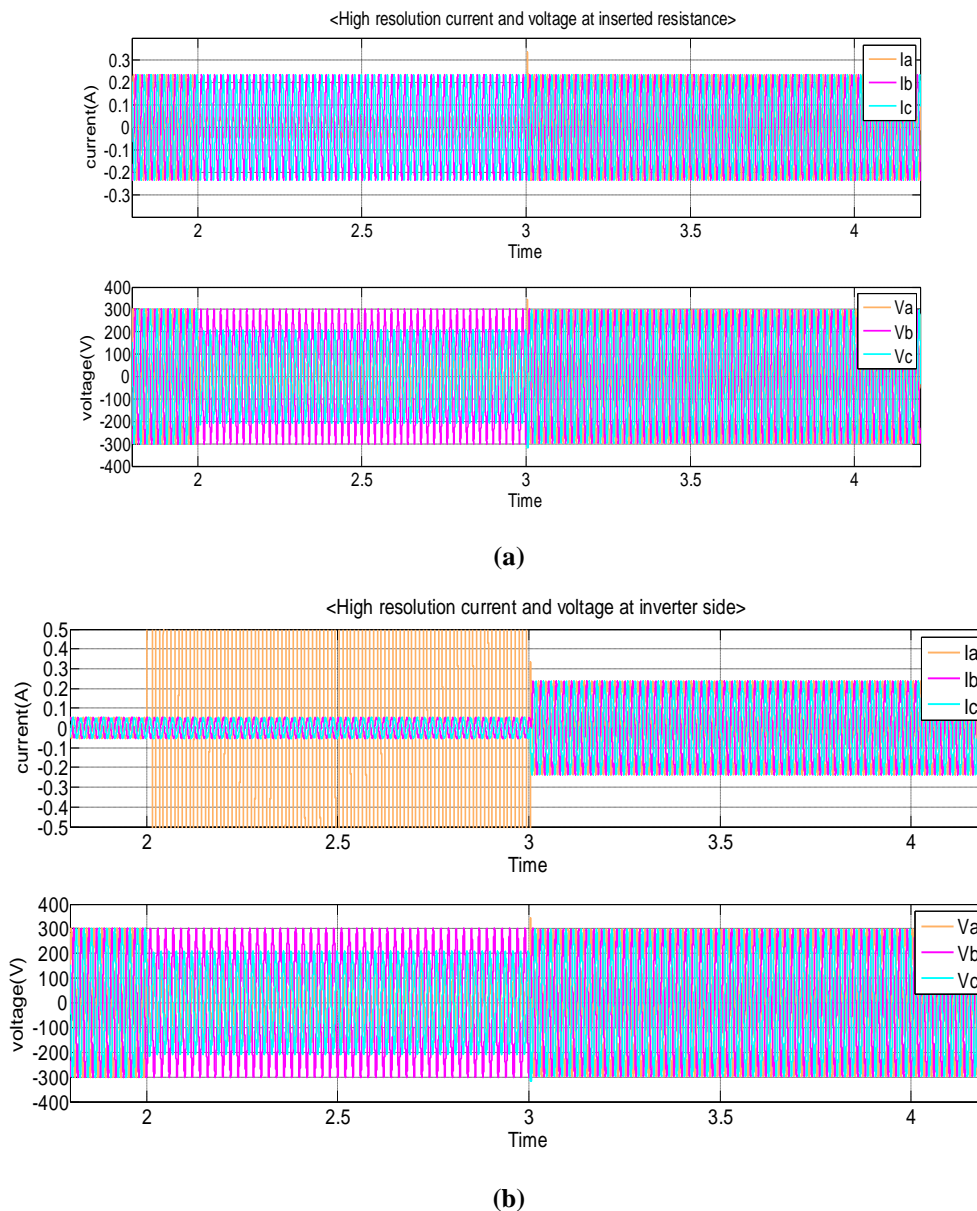

(a)

(b)

Fig. 11 (a) current and the voltage waveform in the inserted resistance to detect the islanding (b) current and voltage waveform toward the inverter side

As per the above figures the current in the inserted resistance and the current at the inverter side is different in the magnitude up to t= 3 sec. After that current magnitude in the inserted resistance becomes equal to the current magnitude at the inverter side approximately 0.2 A. Thus there is no difference in the current magnitude. This

phenomenon shows that the islanding in the system has occurred at t= 3 sec. This can be shown with the help of the RMS values of the current more transparently. The waveforms for the RMS values of the current is shown below:
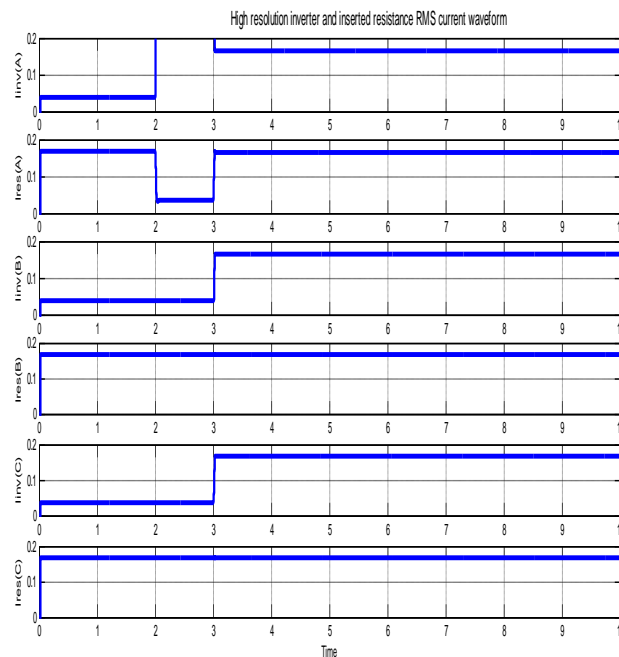

Fig. 12high resolution current waveforms in the phases A, B and C at the inverter side and in the inserted resistance respectively

The above waveform easily explains the islanding phenomenon in the system. Before t= 3 sec there is a difference in the current at the inverter side and current in the inserted resistance because there is no islanding phenomenon occur in the system. But after t= 3 sec the both the current magnitude becomes equal which shows the islanding operation in the system. Thus this is a very simple method based on the current measurement to detect the islanding operation in the system. This method is able to detect the islanding operation without any delay as there is no use of any extra switches or any auxiliary in the islanding detection circuitry in system.

V. CONCLUSION AND FUTURE SCOPE

As this method is based on the current measurement and this is a passive method, this is very fast, simple and accurate method. Also this method have no issue of NDZ (Non Detection Zone). This method do not introduce the perturbation in the system unlike other detection method so this method is free from the power quality distortion in the system. This method also do not disturb by the overhead communication line. Thus overall this method is novel and have many advantages over other islanding detection methods to detect the islanding operation in the system.

This method is chosen for the fault. Development work may be done for other contingency also. Also proper load shedding scheme may be developed to control the frequency and the voltage with in the limit. Load variation effect may also be studied in the system. For generation and load balance other method could also be developed based on the soft computing like GA, ANN, PSO etc.

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