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Improved Islanding Detection Scheme for Multiple Inverter Based DG Systems

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***Abstract*— Islanding operation is most important function of DG connected grid system. So we already develop the islanding techniques, which is based on lot of parameters, in this paper discussed an improved method compared with old techniques. Here a harmonic current disturbance is imposed to grid at one of the harmonic frequency, which is associated with grid voltage. Disturbance imposed by changing the parallel impedance of inverter. Our islanding detection signal is the output current of grid connected inverter at a specific harmonic frequency. In this method does not affect the overall power quality of system, because our harmonic resonance is imposed over a short time interval. We used multiple DG systems, there is no interference between the parallel DG's is observed. The performance of proposed method analised using time-domain simulation carried out in Matlab software.**

I. INTRODUCTION

For improving the power distribution reliability and capability , we considering distributed Energy Resources (DER) including distributed Generation (DG) and Distributed Storage (DS) are, as renewable energy resources. The most important features of DG system is their capability for working in both islanded and grid-connected mode. An important technical issue with DG systems is unintentional islanding operation, so special consideration should be made regarding the safe operation of DG's during connecting and disconnecting to or from the grid [2]. They have lot of methods to overcomes this issues presently, but some have less efficient, more maintenance issues, security problems and also cost problems.

The island can occur when a part of grid is electrically isolated from the power system but the part with island is energized by distributed generators. This condition though helps with continuity of supply to local loads, we can operate the loads without any delays which leads to reducing the lost occurred in our field. The above condition can create some problems like power quality problems (voltage and frequency instability), equipment damages and safety hazards[1]. And it constitutes a great risk for maintenance of power system parts the importance of human and equipment protection, unintentional islanding for DG operation is not tolerated. For these reasons the detection of unintentional islanding is an important concern for DG system in micro grid, operation is required as rapidly as possible to allow the timely disconnection of the DG units [1,2] Islanding is one of the most technical concerns associated with the proliferation of distributed generation connected to utility networks.

They have large number of classification on islanding depending on many factors. Mainly the classification into Remote and local techniques. Remote techniques such as Supervisory Control and Data Acquisition (SCADA), Trip (disconnect) Signal and Power Line Carrier Communication (PLCC) systems. They offer high performance and applicability on multi-source topologies. The main drawbacks of those centralized methods are expensive to implant [5]. Local techniques again classified into passive and active methods which are implemented on the DG side. Passive methods have a large Non Detection Zone (NDZ), this is the main disadvantage of this method, hence are not useful for high DG penetration. A solution for the NDZ reduction is the utilization of active anti-islanding methods. This method is based on injecting a disturbance to grid and then measuring the grid response [1]. Active methods deals with two cases, in first case each DG imposes a small disturbance on grid variable like voltage or frequency which used to detect the operational mode. Second group is based on harmonic injection to grid then to measure grid impedance.

A single-line diagram of the basic system configuration is shown in Fig.1; we assume that the DG system consists of a dc source, an inverter, a filter, a transformer, and a controller. The inverting DG structure connected in parallel to the grid and feeding RLC load at the same time, we can assume that there is large numbers of DG structures are connected parallel for improving power delivering to the grid or load system. The key role in operation play with the help of controller, which helps managing, and protecting the DG system. In normal model, the controller uses unintentional islanding technique which means that once the islanding occurs the DG disconnects itself from the rest of the system to prevent itself and the load. With the help of circuit breaker the DG system will be disconnect from grid system (islanding). After interrupting of CB there will be variations in system voltage, frequency, active and reactive power and THD. In normal cases the voltage and frequency changes can be detected by over/under voltage and over/under frequency relays[3].

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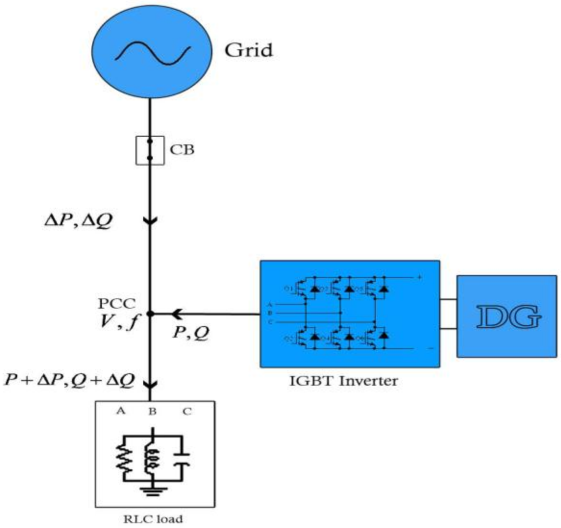


Fig.1 A single-line diagram of the basic system configuration

In normal condition there is no errors occurred in the system, the power produced from DG is delivered to the grid. In normal condition the DG generated power is very less compared with the large load, so the remaining power is consumed the load from grid. Difficulties appear when a load demand and DG generation are close. Now a day's the development of DG recourses improved and also their efficiency also improved. Then frequency or voltage changes can be insufficient to enable detection by inverter. This leads to develop some islanding techniques which can detect these cases when the powers of DG and load are closely matched [3].

In this paper deals with above problem (the generation power from DG and consumption power of load closely matched). Our islanding detection method is a new one which is cope with the active method. One of the attractive active methods is frequency shift method, We introduce a small perturbation in form of phase shift. When the DG is grid connected, the frequency will be stabilized. When the system is islanded, the perturbation will result in significant change in frequency. The drawback of this method is that the islanding can go undetected if the slope of the phase of the load is higher than that of the SMS(Slip-Mode Frequency Shift) line, as there can be stable operating points within the unstable zone[5].

II. DESCRIPTION OF THE PROPOSED METHOD

The concept of the proposed islanding detection method shown in fig.2, a single phase grid connected inverter with an LCL filter. Our present strategy can be used for single phase also three-phase grid-connected inverters interfacing any type of energy resources like renewable or storage system to the grid or load. The idea of the method can also be customized for any type of inverter output filter by considering its control loop. In the fig.2 shows a single phase inverter with LCL filter and RLC load, the grid is modeled as a voltage source which is in series with its Thevenin impedance. The real and reactive power of the RLC load is considered to be equal to the output real and reactive power of the inverter; this is the main principle behind the islanding detection [10,11]. The RLC load is modeled with the resonance frequency of 50Hz and the quality factor of 2.5[9].

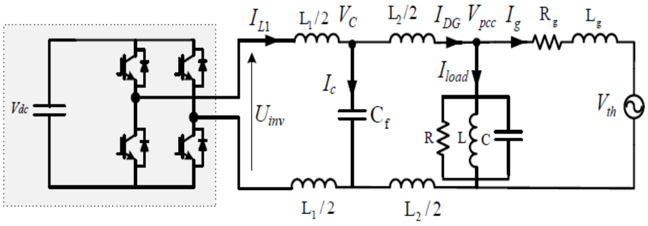


Fig. 2 Grid connected inverter with local RLC load

In our proposed system the dc source considered as renewable energy source system, we assume they delivered a constant output power to inverter section. Islanding of the grid connected generators (photovoltaic system) can occur when the part of utility system having such generators is disconnected from the main grid and independent generators keep to energize the isolated part. The system consists DG sourse, an inverter, a local load (parallel RLC), a switch (breaker, fuse) and the grid. The distribution generation is considered to be in unity power factor operation. Consider the worst case for islanding detection when the active power of load matches to output power of distribution generation. For simulations the worst case is used as test conditions according to UL1741, IEEE 929 and IEEE 1547 [12,13]:

1. The power generated by DG should match the RLC load power, $\Delta P = 0$ and $\Delta Q = 0$.
2. Resonant frequency of the RLC load is the same as grid line frequency (f = 50Hz).
3. The quality factor Q_f of RLC load is set to be 2.5. The quality factor is defined as that the reactive power stored in L or C is Q_f times the active power consumed in R.

Under these conditions, when the grid is disconnected, the distributed generation and RLC load will resonate at nominal voltage and frequency to form an island, unless there is a mechanism to drive voltage at PCC or frequency out of their nominal range [6].

The overall structure of the control system of grid connected inverter is shown fig . we can see that plant model consists single phase inverter with LCL filter and grid. The control system consists of an inner current control loop and an outer dc-bus voltage control loop. The dc-bus voltage control loop is composed of a PI controller which regulates the dc link voltage by providing the reference signal for the current control loop (I_{ref}); however, as shown in Fig. 2, I_{ref} can be externally adjusted for dispatch able resources. The current control loop which is composed of a proportional resonant (PR) controller can effectively track the reference signal which is provided by the current reference generator block in Fig. 2. The frequency and the phase of the reference current (I_{ref}) are determined by utilizing the Phase Locked Loop (PLL) block[1]. The current controller with its harmonic compensators is expressed as:

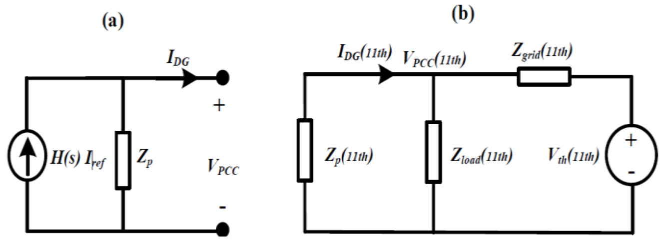
$$G_c(s) = K_{pc} + \frac{K_{ic}s}{s^2 + 2\omega_c s + \omega_f{}^2} + \sum\nolimits_{h=3,5,7,9}\left(\frac{K_{ih}s}{s^2 + 2h\omega_c s + (h\omega_f)^2}\right)$$

As the interface between the distributed power generation system and power grid, grid-connected inverter plays an important role in injecting high-quality power into the grid. In our system an *LCL* filter is placed between the inverter and the grid to attenuate the switching frequency harmonics produced by the grid-connected inverter. Compared with other filter, *LCL* filter has better attenuation of the switching frequency harmonics, which usually yields lower volume and costs, so we adopt *LCL* filter. The resonance of the *LCL* filter requires proper damping methods to avoid the possible instability of the system [7]. So we provide an active damping method which is based on the capacitor current feedback is utilized to prevent resonance conditions. The active damping gain helps to provide a suitable damping ratio in the resonance frequency of the *LCL* filter. Figure shows the proposed islanding detection block is added to the active damping loop which is presented as "intentional resonance creation" block[1].

The output current of current controlled inverter I_{DG}, can be written as,

$$\mathrm{I_{DG}}(s) = H(s)I_{ref}(s) - \frac{V_{pcc}(s)}{Z_P(s)}$$

The reference current and point of common coupling (PCC), are considered for determining output current of inverter. H(s) referred to as closed loop transfer function . We know that there is harmonics occurs in grid system, so these harmonics of V_{pcc} cause current harmonic according to the magnitude of $Z_p(s)$ at any harmonic frequency, the equivalent parallel impedance of inverter takes a very low value at a given harmonic frequency , the THD (total harmonic distortion) of the output current increases.



Fg.3 (a) closed loop model of grid connected inverter, (b) equivalent circuit of system

The main principle behind of our proposed islanding detection method is, there is an active damping loop which is created by capacitor current feedback gain can affect the transfer function of the grid connected inverter. The feedback implementation can control output harmonic currents[1].

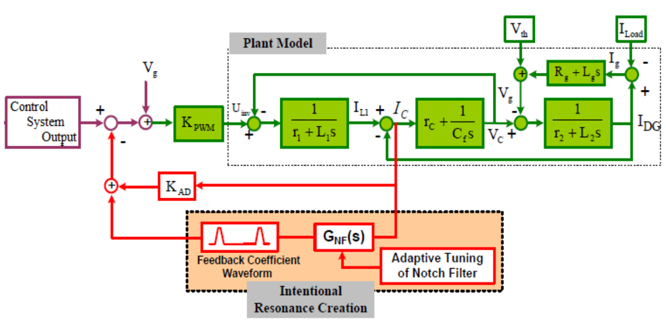


Fig.4 proposed system configuration

In our proposed method, we intentionally create a harmonic resonance on the output current of inverter at a specified frequency namely f_{res} which is associated with one of the odd harmonic if the grid voltage. Our harmonic frequency is a selectable value, the resonance creation can be done by an appropriate feedback implementation in control system of each grid connected inverter.

In normal condition of grid , they have some harmonics are present. We considered these harmonics for our concern, we consider the case of grid disconnection, the source of harmonics of grid voltage is not present anymore. So, output current of the inverter at does not change. In grid-connected mode during which the grid voltage is contains odd harmonics. The root mean square (RMS) of the output current of the inverter is changed in both mode of operation, so that these is taken as the islanding detection signal.

For islanding method purpose the harmonic resonance is imposed over a short time interval while the inverter current at f_{res} is measured at the same time interval. The harmonic resonance is imposed over a short time interval, so THD of the inverter current is not significantly affected. Our method is different from previous methods which are based on the measurement of the voltage THD. Voltage THD measurement method depends on parameters like grid impedance and harmonics of the grid voltage, while due to the adaptive tuning ability of feedback parameters (used in our system), the performance of the proposed method is not markedly affected by these issues (grid impedance and harmonics of the grid voltage). We can be concluded that, though, harmonic content of DGs' currents affected due to the grid parameters; the adaptive tuning of feedback parameters can compensate this effect. Our harmonic resonance current is created by changing the equivalent parallel impedance of the inverter. The parallel impedance adjusted by use of a feedback from the capacitor current of the inverter's output filter at f_{res} . The important feature is that, resonance frequency should be far from both the fundamental frequency of the system and the resonance frequency of the admittance seen from the grid. For this the inverse of a second-order notch filter which is tuned at f_{res} is used.

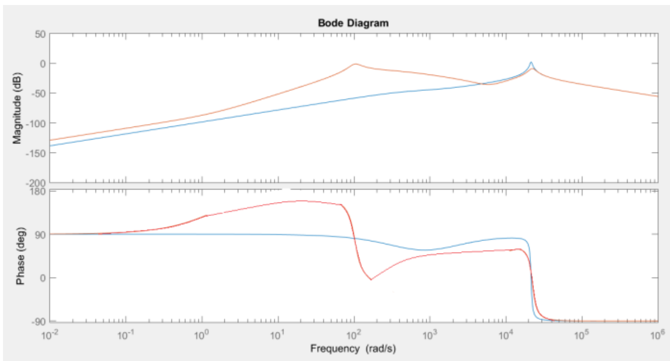


Fig.5 equivalent parallel admittance of inverter with and without notch filter-based feedback

The block diagram consists of plant model and all control loops of system. We derive all algebraic equation in s domain by all linear differential equation of plants and controllers. Arbitrary transfer function can be formed with the help of

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mason's gain formula [1,8]. Bode diagram of the equivalent parallel admittance of the inverter with and without notch filter (resonance creation loop) is shown in fig. we can seen that notch filter leads to a considerable decrease in the magnitude of the parallel equivalent impedance at f_{res}. The decrease of parallel impedance results in remarkable increase in the harmonic component of output current of inverter, this is our islanding detection signal. We already say that harmonic resonance is imposed over a short time interval for fulfill the power quality. For this, the feedback coefficient is periodically changed. In an complete cycle there are two regions, one is islanded other is non-islanded. The islanding condition is checked by imposing the harmonic resonance on the inverter current .if the period of feedback coefficient deceases, get fast islanding detection. This damage the power quality of system, for obtain better power quality during harmonic resonance imposing , the quality factor of notch filter is tuned to preserve an acceptable THD of current.

In our basic system only consider the RMS current of inverter at a specific harmonic frequency (NF_c). When the grid voltage harmonic current order might be equal to non linear load, in these case islanding detection procedure malfunctioning. To overcome these problem, we measuring the THD of inverter terminal voltage. If there is any frequency variation in the system, so we adopt a frequency checking unit also. The overall islanding detection procedure is shown below flowchart.

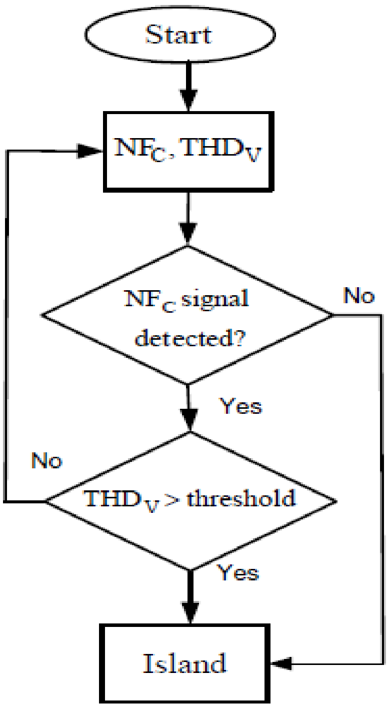

Fig 6.Flowchart of modified proposed islanding detection method

From the flowchart, when there is no NF_C is detected, the grid connected inverter is in the islanding condition. When NF_C is detected, the follows two situations;

1. If the system have no local nonlinear load, THD_V will be lower than pre-defined threshold (inverter is still grid connected mode)
2. If the system consists nonlinear load, the load current have same harmonic current component. In this case, THD_v is smaller than pre-defined threshold (non-islanding reported).

III. PERFORMANCE OF THE PROPOSED METHOD FOR MULTIPLE DG SYSTEMS

Fig.7 shows the equivalent circuit of the system with n-parallel inverters. This inverters output is commonly connected in point of common coupling. At this point our load is located and also the grid section is connected. There is a circuit breaker is placed among the point of common coupling and the grid section. Which determine the system is islanded or not. We believe that the total real and reactive power of RLC load and parallel inverter are same. And also the parallel impedance of the grid connected inverter is capacitive at frequencies lower than the resonance frequency of the filter, so that a resonance among these inverters and the inductive impedance of the grid (Z_{grid}) is likely at a certain frequency that increases the injected current to the grid at this frequency [1]. The interaction between the inverter and the main grid can be explained by a transfer function given [22];

$$H_{series-Resonance}(s) = -\frac{I_{DGi}}{V_{th}}|I_{refi=0}\,, \qquad i = 1,2,\ldots.N$$

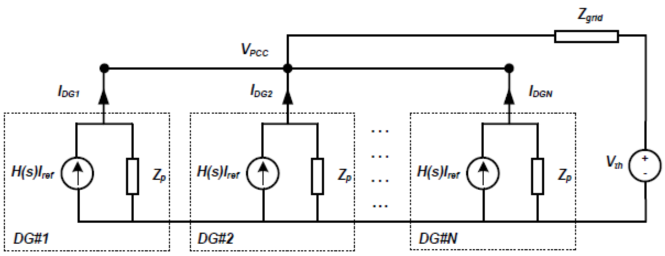

Fig.7 equivalent circuit of the system with n-parallel inverters.

IV. SIMULATION RESULTS

In this section we validate the effectiveness of our proposed islanding detection method, a multiple inverter based DG system with three DGs has been simulated in simulink software. The dc-link voltage of each inverter can be considered to be constant, in both inverters dc-link value should be same. This is help to simulation scenarios. We can replace this dc-link value to a renewable energy resources like solar energy, wind, tidal, etc. for this replacement we also consider it's control strategies. The power ratings of all inverter should be equal in this case. The parameters of our proposed method should be given in below tables. The THD value of grid voltage is 5% the amplitude of inverter injected to grid is approximately 10A.

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Parameters	Symbols	Values
Inverter side inductor	L_1,r_1	10mH,1Ω
Filter capacitor	C_f, r_c	50μF,50mΩ
Line side inductor	L_2,r_2	2mH,1Ω
Grid impedance	L_{grid}, R_{grid}	.02mH,.05Ω
Grid voltage	V_{grid}	230V
DC link voltage	V_{dc}	415V
Parallel RLC load	R,L,C	10Ω ,20H,1 μF

Table:1. Parameters of the circuit of the inverter

Parameters	Symbols	Values
PR current controller	K_{pc}	20
	K_{ic}	4000
	ω_c	3rad/s
Active damping gain	K_{AD}	2
Notch filter coefficients	K_{NF}	6
	a	12000
	b	33.3

Table:2. Filter specification for islanding detection

The performance of the proposed system for the islanding detection technique is validated by MATLAB Simulink software. Figure 8 shows the simulated diagram of the system.

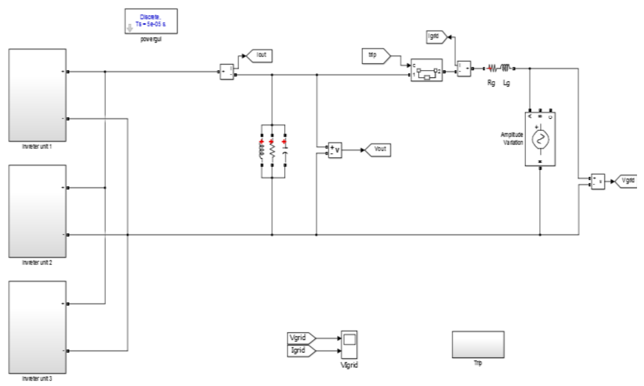

Fig 8. Simulated diagram

Simulation section A and B are done for non-linear loads with considering normal and grid disturbance condition. In both cases DG provide a constant supply. In grid disturbing case consists RMS current different based and also THD_v considering cases are discussing. In all condition our RLC load condition satisfying some standard test (consumption and generation balance of real and reactive power). Resonant frequency of RLC load is 50Hz, and the quality factor of 2.5.

Our islanding detection do with the help of a inverse second order notch filter. This filter is designed by multiplying inverse transfer function of two notch filter, which is expressed as:

$$G_{output-INF}(s) = K_{output-INF}\left(\frac{s^2 + a_1 s + w^2}{s^2 + b_1 + w^2}\right)\left(\frac{s^2 + a_2 s + w^2}{s^2 + b_2 s + w^2}\right)$$

A. Normal operation (without trip)

In this case the multiple inverter set is connected to a RLC load. We assumed that the power rating of DG and the consumption load of RLC circuit are same. In this case if the load consume energy from DG continuously.

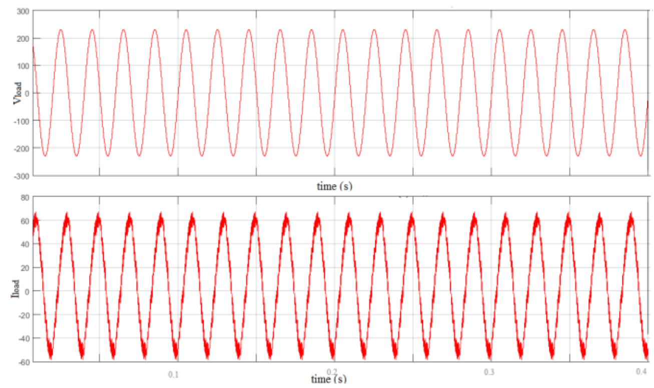

Fig 9. Load voltage and current waveform in time basis in normal operation.

The notch filter operation is based on capacitor current feedback, the bottom fig,. shows the capacitor current in normal operation. We can see that here is no fluctuation obtain in capacitor current. That means there is no feedback changing in the circuit. So no islanding operation obtained in the circuit.

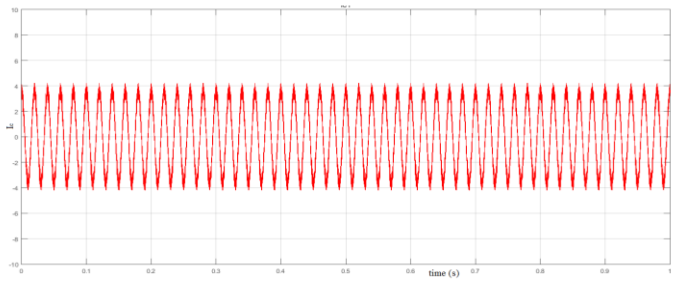

Fig 10. capacitor current on normal operation.

B. Disturbed amplitude variation in grid

In these case we need a circuit breaker for proper operation of Islanding. We consider two types of amplitude fluctuation in grid side , one is under voltage case other is over voltage case. In our case at the time interval 0.1 to 0.2 sec obtain under voltage case, at 0.3 to 0.4 time interval we obtain over voltage fault. In both case the CB will operate (open) and disconnect the grid to our load section. At these time the grid current falls to zero. We can see it fig.…

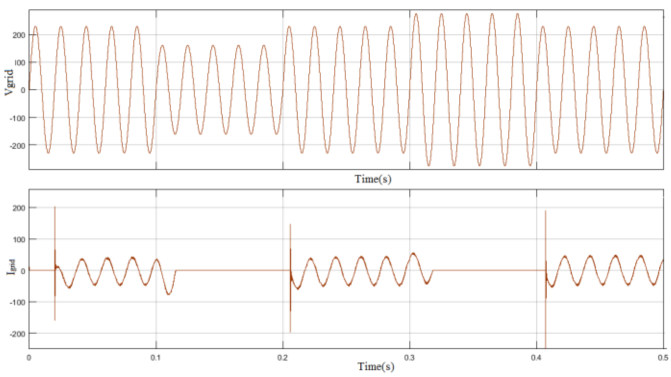

Fig 11. Disturbed amplitudes in grid voltage corresponding grid waveform in bottom

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At the above condition, the DG will delivered power to load section for proper operation. These conversion operation obtain within a short time intervals. We can see the load current and voltage waveform on both situation. We assumed that the power delivered from DG and power consumption of load should be equal. The power values in both islanded and non-islanded condition are same. The region of islanded (time interval 0.1-0.2sec and 0.3-0.4sec) section the current value is obtain from DG, that is the maximum power rating of the DG. In Fig.13 shows the capacitor current variations in operation. There is a change of capacitor current in the time of islanding condition. In our system islanding is based on the capacitor current feedback, if the grid variation occurred in the system the capacitor current waveform also change. Based on these the islanding occurred.

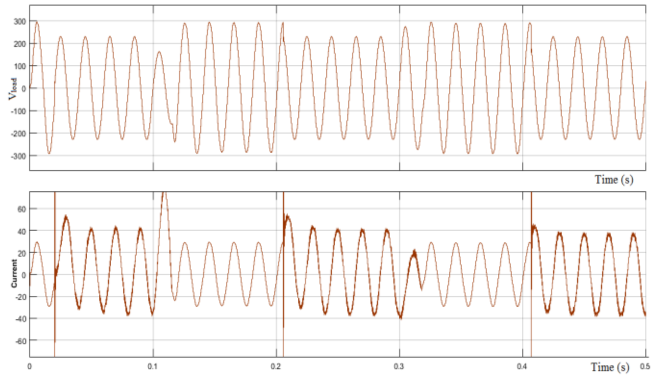

Fig 12. Voltage and current waveform across load in the time of corresponding amplitude variation

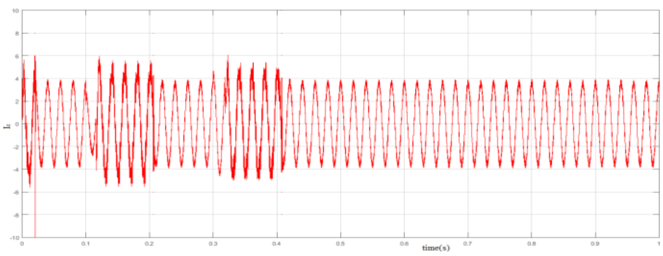

Fig 13. capacitor current waveform during faulty condition

C. THD variation

If the order of the harmonic currents associated with the nonlinear load be equal to grid voltage which result malfunctioning of our islanding detection. For prevent these case we adopt measurement of THD of inverter terminal voltage. We set a harmonic order of range 8%, if the THD value greater than our range, then grid connection should reconnect. This condition is set in bottom figure. The time interval of 0.1 to 0.3sec the grid voltage occurs large harmonics. At this time the circuit breaker will open, grid isolated from load section, the current value on grid down to zero range.

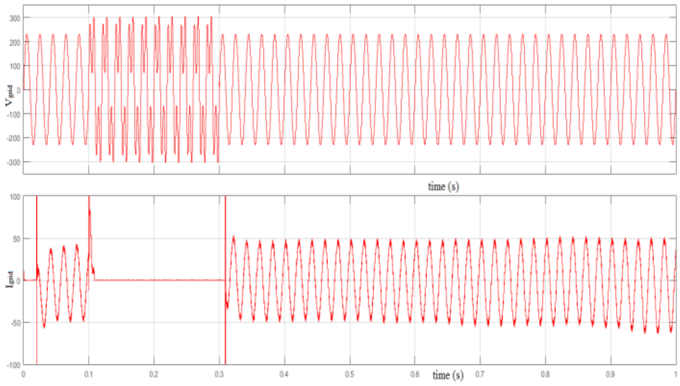

Fig 14. grid voltage and current on both operation

Fig.15 shows corresponding load voltage and load current. At the time of islanding the power delivered to the load is done with DG system. We assumed that the power generation from DG system and the power consumption of load is same (Islanding std.).the load continuously operate without any power deviation. This is the main advantage of our proposed system. The switching time from normal operation (grid tied) to islanded taking minute seconds, so there is no power fluctuation in the load circuit.

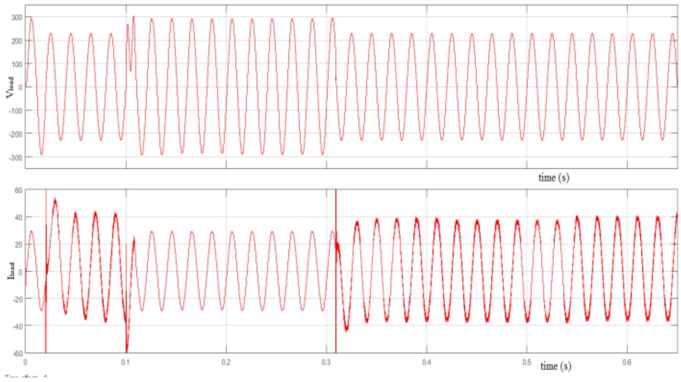

Fig 15. voltage and current waveform across load during both operation

The islanding operation is based on capacitor current feedback. So the variation of capacitor current is properly detected and corresponding signal is produced with the help of notch filter. Bottom fig shows the variation of capacitor current in both mode of operation.

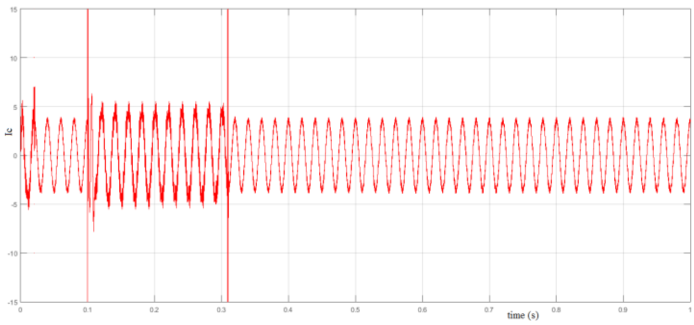

Fig 16. capacitor current waveform on both operation

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V. CONCLUSION

In prior islanding detection method is based on voltage and frequency measurement units. In case of any generation and consumption imbalance in the islanded system, the voltage and frequency protection unit will detect the islanding condition. For this we need lot of protection devices in each multiple inverter systems, the advantage of the proposed method is more pronounced for the situation where there is a power generation and consumption balance in the islanded mode. In our system loads are not damaged since the voltage and frequency of the islanded system will remain in a required range.

Our proposed islanding detection method suitable for using in both single and multiple DG systems have been proposed. The islanding detection system can creating a controlled harmonic resonance at the output current of the inverter at a specific harmonic frequency. This resonance current is periodically imposed to the grid by changing the equivalent parallel impedance of the inverters. The output current of the grid-connected inverters at this specific harmonic frequency is used as our islanding detection signal. The the overall power quality is not significantly affected because of harmonic resonance is imposed over a short time interval. In our proposed method there is no interference among the parallel DGs was observed which makes it well suited for the application in systems involving a large number of parallel inverter-based DGs.

The proposed islanding detection scheme is characterized by some features for efficient choice for multiple-DG systems:

- There is no interference among parallel DGs is observed and the islanding detection system shows a good performance in multiple-DG systems
- DGs located within any place of the proposed islanding detection system can properly work in the presence of other DGs equipped with any type of islanding detection scheme.

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