A NOVEL CONTROL APPROACH FOR GRID-TIED AND ISLANDING OPERATION OF DISTRIBUTED ENERGY RESOURCES

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Abstract-
This work provides an enhanced control technique for a three-phase inverter in distributed energy resources that can function in both grid-connected and islanding modes. Neither the crucial islanding detection nor the independent operation of the two controllers are required. A voltage control loop and an inner inductor current loop that may operate in a synchronous reference frame (SRF) make up the advanced control method. Normally controller is operated as current controller in grid connection mode and it will automatically operate as a voltage controller to control the load voltage when islanding is formed. Load current and voltage waveform are distorted due to the presence of non-linear load,this problem can be resolved by using the load current feed-forward control technique and it can improve the load current and voltage waveform and reduce the power loss due to the elimination of lower order harmonics. The advanced control strategy can be validated by the use of simulation results.

Keywords-
Three–phase Inverter, Distributed Generation (DG), Photovoltaic Module (PV), Energy Storage System (ESS), Synchronous Reference frame (SRF), Total Harmonic Distortion (THD), Critical Islanding Detection.

1. Introduction

Distributed generation (DG) is very popular nowadays because of its high reliability. In the event that non-conventional energy sources like solar panels, wind, fuel cells, microturbines, tide power, and geothermal energy become accessible, it will become a competitive substitute. [1-2]. Distributed energy resources (DER) is defined as the production of electricity by smaller than central power generating plant can permit connection at any point in the distribution power network [3]. All of these renewable resources are connected through a power electronics converter circuit such as a 3-phase inverter. Distributed generation can be operated in both grids connected as well as islanding mode. In grid-tied mode distributed generation supplies power to both grid and local critical load. When any interruption in the grid side happens then it is necessary to find out critical islanding and separate the utility through the distributed generation system as quickly as possible. It is essential to keep the power supply functioning in order to increase its reliability to local critical load even if the utility becomes outage due to any reason. A microgrid consists of distributed generation, energy storage, multiple linked loads, and sophisticated control systems that can function in both grid-connected and island mode. [4].

The main concern related to distributed generation is the load voltage, which is controlled through the grid of utilities when operatingin grid-linked mode but if islanding happens the load voltage is now controlled by distributed generation, transient in the load voltage should be reduced as soon as possible by controlling the load voltage to its rated value and this is the main challenge for operation of distributed generation[5-6].It is suggested to synchronize using a hybrid phase-locked loop and elimination of harmonics in the calculated frequency and phase.Current and voltage controllers both employ sliding mode control. Lyapunov theory is used to examine the stability of both voltage and current loops [7].

Drop based control approach, which this study refers to as the voltage-controlled mode, is employed for power sharing among dispersed generation and utility for local essential load. It is also used for power sharing between parallel connections of inverters..

The inverter in the voltage-controlled loop functions as a voltage source, and voltage should be sustained at its rated value while shifting over to the current-controlled mode from the voltage-controlled one.

Main restrictions of this method are poor dynamic performance and grid current is also not controlled properly by this method. Inrush current, when switching from islanding mode into grid-connected mode is also the main concern even when using a phase-locked loop and virtual control.

Sometimes researchers use hybrid voltage controller as well as current controller, in which a voltage controller or a current controller is utilized; therefore, whenever the operation mode changes, the controller must be adjusted. One set of controllers controls the inverter as a current source, while another set controls it as a voltage source. [8]. This strategy could work well for controlling output current in grid-connected mode and eliminating inrush current, although it won't work well whenever grid current is taken into account. The main issue in hybrid control mode when outage occur then the controller is swapped to voltage control mode and during the transition of swathing neither is the load voltage controlled by grid nor by distributed generation, hence voltage will rise for this time is depend on the islanding detection method, how fast islanding can be detected the accuracy will be better [9-11]. Poor grid current and load voltage waveform is also the main issue for the hybrid control method. But when linked to a grid, the local load current should willbe sinusoidal and hence we need to inject harmonic current through the distributed generation into the grid to mitigate the total harmonic distortion.

In islanding mode due to non-linear load, load voltage waveform is distorted and various methods is used to improve the issue such as sliding mode control, resonance controller, multiloop control method etc. but this method either control the load voltage quality or grid current quality and improve current waveform and voltage waveform both are not possible [12-13].Integration of large number of distributed generation in to grid increase high penetration in power system and power stability of system is reduced. Master-slave droop advanced control method is used for regulation of frequency , genetic algorithm is also used to improve the paramrters of droop strategy and improved frequency regulation and stability is improved[14].

This paper presents new controlled strategy that removes the above problem. The 3-phase inverter is first controlled by a current control loop, which also acts as a constant current source in the synchronous reference frame(SRF).In order to set the desired reference signal for the inner inductor current loop, a second voltage controller is used. Additionally, proportion plus integral controllers for the D and Q axes are utilized. Within the grid-connected mode, distributed generation is operated as the current source and load voltage is supervised by the grid. Voltage controller in the D-axis has reached saturation and the Q-axis is zero due to a phase-locked loop. As a result, the set value of the inner control loop of current is not regulated by the voltage controller. When an outage occurs, the grid cannot detect the load voltage; as a result, the voltage controller is triggered and will be operated as a voltage source. It is automated to convert from current-controlled to voltage-controlled mode, so there's no need to rapidly and precisely figure out the key islanding detection approach. The primary benefit of this new technique is it will utilize both the current controller and voltage controller and dynamic response is also very good as juxtaposed with voltage mode control only. Third, load current feedforward is also used to improve the grid current waveform in which load current signal is injected in the current reference. Within the grid-linked mode,In order to reduce the harmonic current, distributed generation injects current into the grid. This technique is also applied to enhance the load voltage quality in islanding mode.

2. PROPOSED CONTROL STRATEGY

This paper presents new controlled strategies which are operated in islanding mode and grid-connected mode. Schematic diagrams of the controlled strategy with three three-phaseinverter are given in Figure 1.

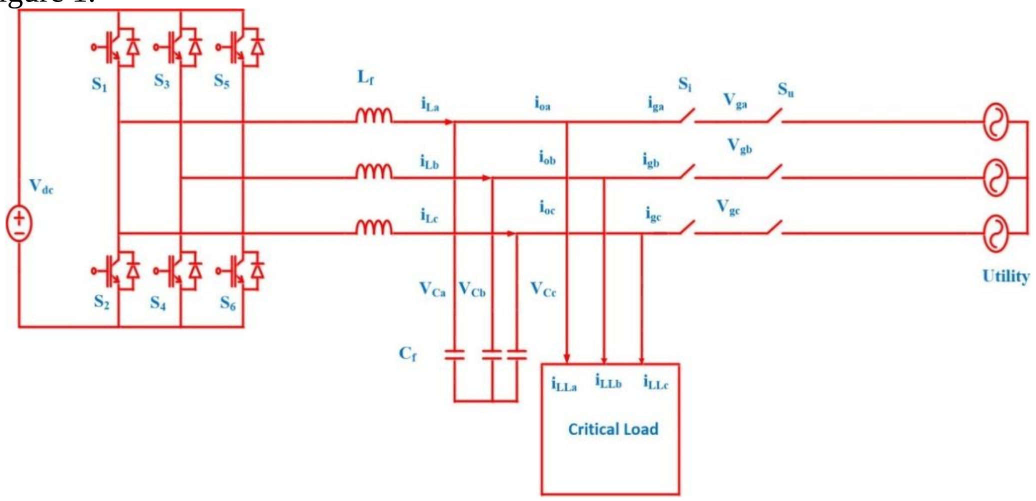

Figure 1. Block diagram of distributed energy resources based on new control method.

Distributed generation is connected with 3-phase inverter along with passive filter(LC). Thephotovoltaic energy is converted in electrical energy and this changed to DC by the front end power converter, and it regulates the dc voltage. After that It is exemplified by constant dirct current voltage source V_{dc}. In AC side of the 3-phase inverter critical load is linked across the utility.

In this figure-1, there are two switches utility protection switch s_u and the other is inverter transfer switch s_i. In a normal situation both switches are ON When a utility outage occurs then utility transfer switch is OFF when islanding is confirmed by the islanding detection technique then inverter transfer switch gets OFF. Hence distributed generation goes grid-connected into islanding mode. Whenever a utility outage is retrieved then first of all distributed generation should synchronize after that inverter transfer switch s_i is gets ON and connected through the grid.

To provide the desired power P_{DG}+ jQ_{DG} in the grid-connected mode The total power generated by distributed generation P_{DG}+ j$Q_{DG}$is equal to power supplied in load demand P_{load}+ jQ_{load}_load as well as the power supply to the grid P_g+ jQ_g. The three phase inverter is employed as a constant current source in this process.

Suppose load connected to distributed generation is in parallel with RLC circuit the,

$$P_{load}=\frac{3}{2}.\frac{V_m{}^2}{R}\text{.....................................} (1).$$

$$Q_{load}=\frac{3}{2}.V_m{}^2.\left(\frac{1}{\omega L}-\omega C\right)\text{........................} (2).$$

Were,ω is the frequency of the load voltage and $v_m$is the amplitude of the load voltage. When local critical load is fed then still it will be equivalent to the parallel RLC circuit by taking fundamental component.

When there is outage happen to the grid then the distributed generation is transition from grid tied mode to islanding mode and in this interval load voltage is nether control by distributed generation nor

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controlled by utility and hence there will be voltage rise during this interval. As when grid connected mode power generated distributed power is supply to both grid and local critical load, but when islanding is formed then grid power is zero and total generated power is given to local critical load only, due to increase in power at the load terminal then voltage and frequency will be increase which may damage the load. When during the transition of grid connected mode to islanding mode till the islanding happened the distributed generation is controlled as a current controller and hence power changing can be controlled and voltage excursion can be eliminated. This idea will be used in this paper.

In this paper new controlled strategy used in which output power is always controlled by controlling the current of the inductor and voltage and frequency is monitored. When islanding happen the voltage and frequency may drift from the normal range but it can be come to normal range automatic by regulating the output power.

3. CONTROL SCHEME FOR 3-PHASE INVERTER:

Block diagram of novel control strategy is shown in figure 2 in which load current i_{Labc} ,load voltage V_{Cabc} ,inductor current i_{LLabc} and utility voltage V_{gabc} are sensed. The 3-phase variable is represented by DC quantities and the inverter will be controlled in a synchronous reference frame (SRF).control diagram is represented by the current reference generation model, phase locked loop and inductor current loop control.

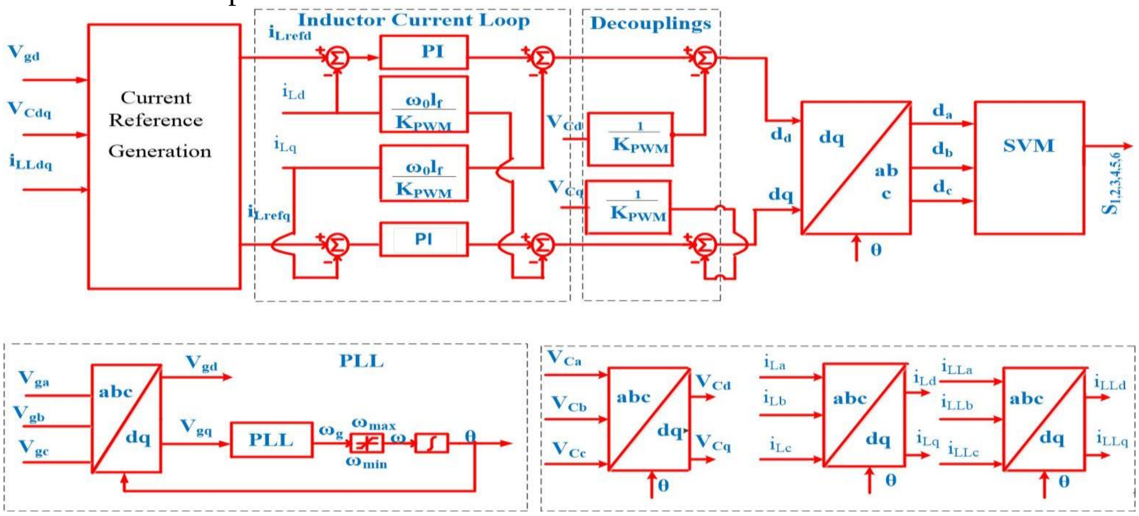

Fig 2. New control strategy Block Diagram

In this control scheme reference current for space vector modulation is generated by the current reference generation module. The error signal produced by the reference signal and actual inductor current passes through the PI compensator of the Direct axis and quadrature axis. The coupling effect due to the inductor can be mitigated by the decoupling effect denoted by $\frac{\omega_0 L_f}{K_{pwm}}$ and coupling due to capacitor can also be decoupled by $\frac{1}{K_{PWM}}$.Switches of 3-phase inverter are controlled by the output of the state vector modulation (SVM). Where, $K_{PWM}$is the voltage gain of the three phaseinverter and its magnitudeis half of the direct current voltagevoltage. To find out utility voltage and frequency synchronous reference frame (SRF)with phase locked loop (PLL) is employed. In current reference generation model a limiter is used to lock the frequency of the load voltage inside rated value.

Inthis figure- 2, We regulate inductor current according to desired current value. When current reference is constant than it will acts as a constant current source but when islanding is happened then current reference is regulated to control the power output so that voltage excursion will be mitigated.One unique feature of this paper is that it can also be utilized in islanding mode since it can

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modify the desired current value to meet power demand among utility with local critical load. A load current feed-forward can also be used to mitigate the harmonic current and load voltage ripple.
In figure 3 current reference generation model is shown which can operate grid operated mode and islanding mode. In this model PI compensator are used in Direct-axis and proportional-compensator are used in Quadrature -axis and current limiter are used in D-axis to limit the current to rated value. In final inductor current reference load current are added to implement load current feed-forward. The unique feature of this model is there is no need to critical islanding detection to seamless power transfer and other benefit is to power quality improvement due to load current feed-forward current reference generation model consists of mainly four-parti. Current flowing through the filter capacitor ii. Voltage controller output iii. Grid current reference iv. Load current.

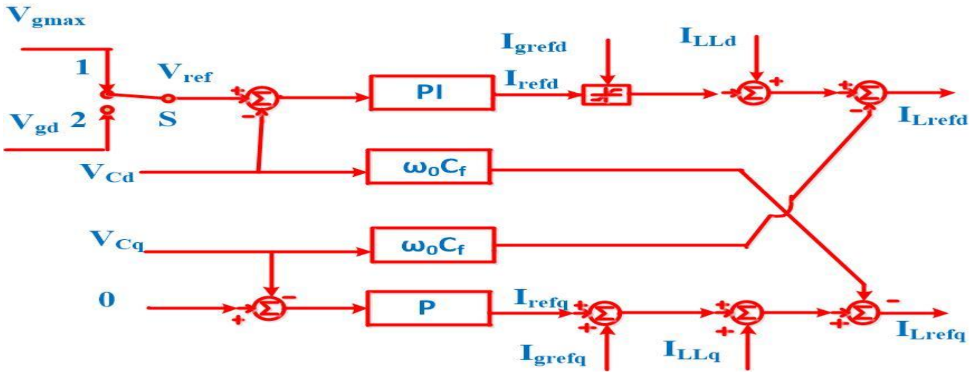

Figure 3. Current reference generation model.

In grid-connected mode load voltage is controlled by a grid that's why the current reference is not dependent on load voltage and itoperated as a constant current source because voltage to the PI compensator gets saturated and the p compensator is zero. When islanding occurs, current reference is regulated to its desire value and voltage controller is automatically controlled and inverter operated as a voltage source. As in theproportional integral compensator is connected in the direct-axis and the proptional-compensator is connected to the quadrature-axis the voltage controller is inactive in grid-linked mode but whenever there is a power outage voltage controller is automatically activated. Hence no need to switch the current controller and voltage controller individually and also no need to find critical islanding detection.

4. SIMULATION RESULTS

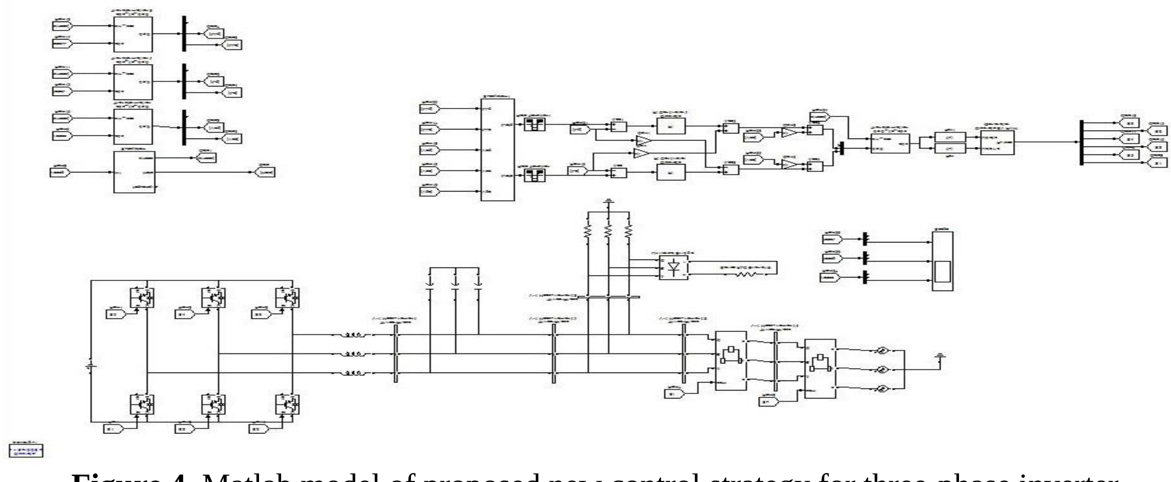

Figure 4. Matlab model of proposed new control strategy for three-phase inverter.

The planned control strategy has simulated in MATLAB/SIMULINK to investigate the feasibility.For simulation, here we have taken a 4 KW rating three-phase inverter.we have taken 230 V line voltage

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and reference voltage has been taken 10% higher value. Rated frequency has been taken 50Hz and for the limiter, it may be .3Hz higher or .3 Hz lower value than the normal rated value. The parameter table is given below.

Table1. Parameter and its value.

Parameters	Value
Reference voltage maximum V_{max}	230 V
Rated reference current I_{Gref}	10 A
Minimum limiter frequencyω_{min}	50.3× 2π rad/sec
Maximum limiter frequency ω_{max}	49.7× 2π rad/sec

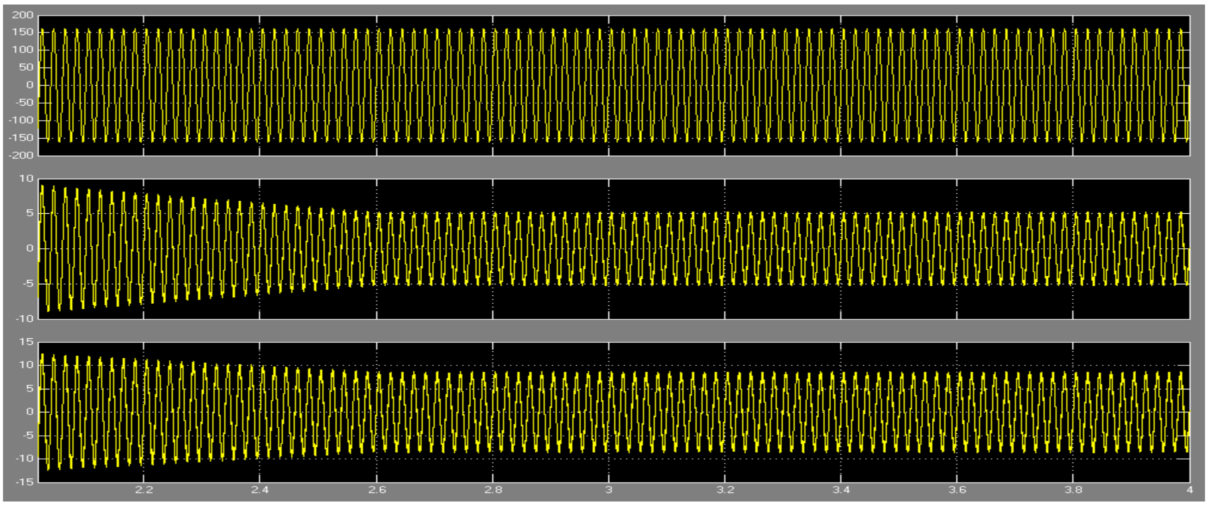

Figure 5. simulation result waveform of conventional voltage mode for(a) load voltage (b).Grid current(c)Inductor current.

In figure5. we can see that the current reference is changed at 14.5 sec but it is observed that the dynamic process is goes till 15.7 sec, this problem can be rectified by new controlled strategy which are given in figure 6.

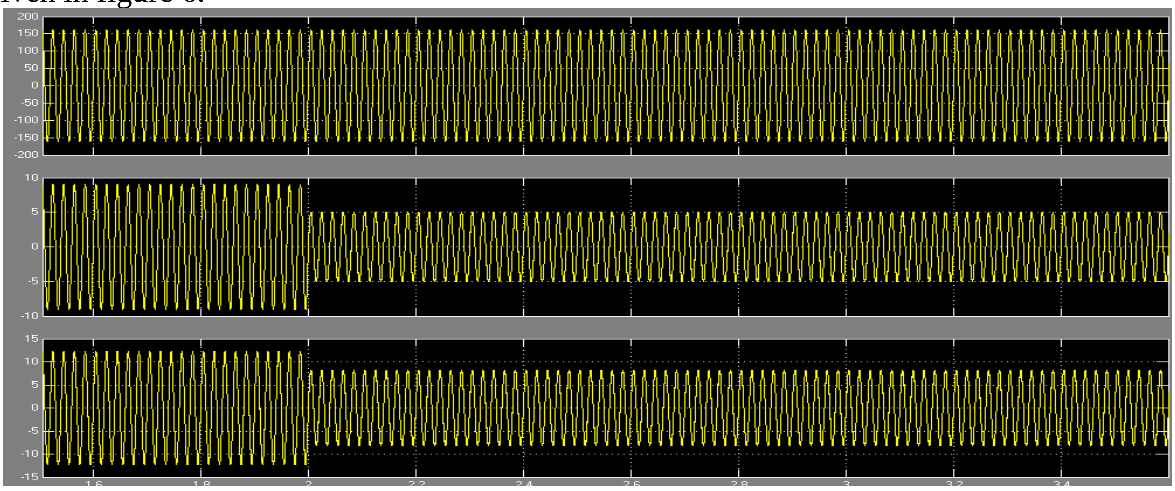

Figure 6. simulation result waveform of new controlled strategy for (a)load voltage (b).Grid current (c)Inductor current.

In figure 6. simulation waveform of the new controlled strategy has been given in which the time duration of the dynamic method is less than six milli-seconds which is much less than that of the conventional controlled strategy and hence switching into islanding mode from grid-connected mode is smoothly because of which voltage excursion will reduce.

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In this planned controlled technique feedforward load current is applied due to which load voltage waveform and grid current waveform have been shown in Figure 7.below.

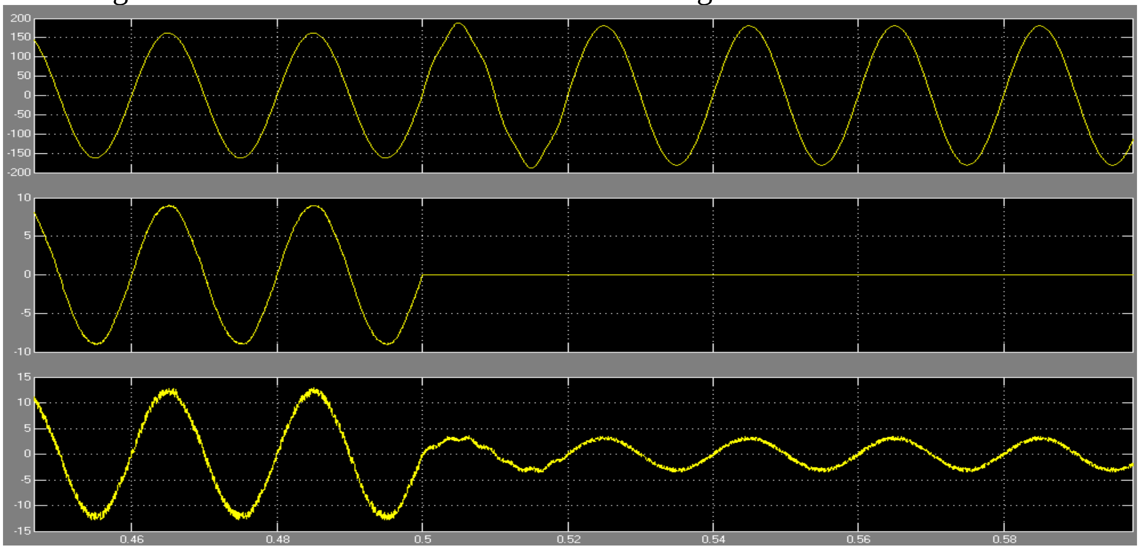

Figure.7. when distributed generation transfers from grid-linked mode to islanding mode then (a) critical load voltage(b)grid current waveform(c). inductor current waveform.in hybrid voltage and current controlled mode.

The load voltage and grid current waveshapes are substantially are heavily distorted in conventional hybrid current and voltage control mode, resulting in a total harmonic distortion of around 7%. Due to high THD the losses increase and the efficiency of distributed generation decreases. The power factor of the system is low due to this effect. It can also be reduced when the planned control technique is used along with distributed generation.

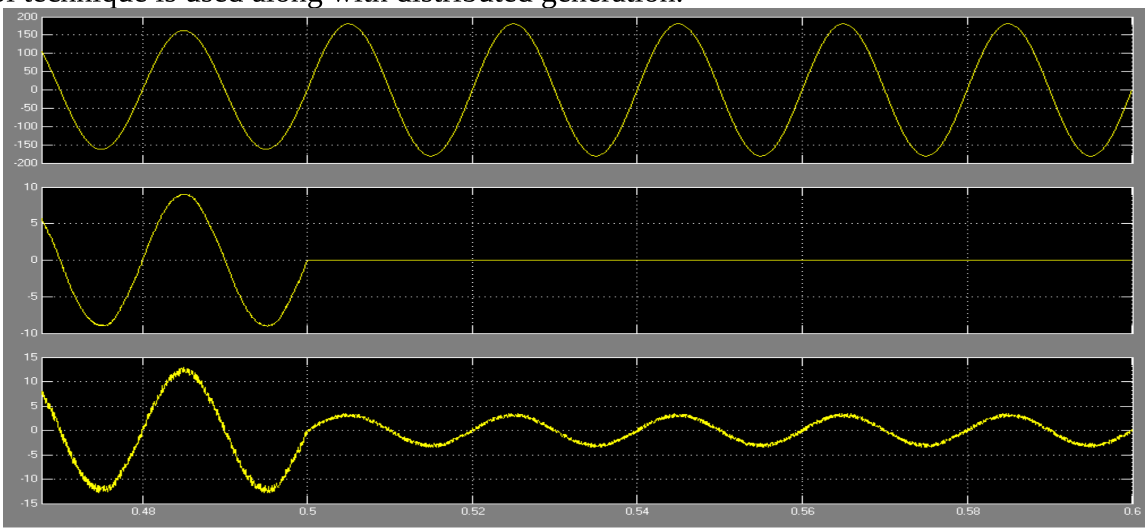

Figure 8. when distributed generation transfer from grid-connected mode to islanding mode then (a) critical load voltage (b) grid current waveform(c) inductor current waveform in proposed controlled strategy.

In figure 8. we see that the waveform of the load voltage and grid connect is not distorted and is very smooth than that or conventional strategy that's why the total harmonic distortion is very low as compare to conventional strategy. It will around0 · 7%. Power factor of the system is increases and losses is reducing.

5. CONCLUSION

A new control strategy has been developed which can be operated in grid-connected with islanding modes, there is no need to switch the controller individually in grid-connected and islanding mode. Voltage source controller is inactive in the grid-connected mode and inverter acts as a constant current source. When an interruption of utility happens the voltage controller turns on automatically and inverter works as a voltage source It has a very fast dynamic response and voltage excursion due to utility outages has been mitigated. Load voltage waveform in islanding mode and grid current waveform in grid-connected mode have been improved by load current feedforward current. Results from the simulation confirm the new regulated technique and our efforts have produced good outcomes.

6. References

1. A. Yadav, L srivastava “Optimal placement of Distributed Generation An Overview and Key Issues” International Conference on Power, Signals, Controls and Computation (EPSCICON), 8 – 10 January 2014.
2. S.A.Eroshenko,A.I.Khalyasmaa “The improvement of distributed generation integration efficiency”11th IEEE International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG) 2007, pp, 2166-9546,01 May 2017.
3. Mahmoud, M., Azher Hussain, S., &Abido, M. , “Modeling and control of microgrid: An overview” Journal of the franklin institute,2822-2859,2014.
4. Bayindir, R.,Hossain,E. , KABALCI , E. & Perez, “a comprehensive study on microgrid technology” International journal of renewable energy research,1094-1107,2014.
5. I. J.Balaguer ,Q.lei,S.Yang,U.Supatti,F. Z. Peng “ Control for Grid-connected and intentional islanding operations of Distributed power generation” IEEE Transaction on industrial Electronics, volume :58 , issue:1 , pp. 147-157, jan.2011.
6. S. Alepuz, S. Busquets-Monge, J. Bordonau, J. A. Martinez-Velasco, C. A. Silva, J. Pontt, J. Rodriguez, "Control strategies based on symmetrical components for grid-connected converters under voltage dips", *IEEE Trans. Ind. Electron.*, vol. 56, no. 6, pp. 2162-2173, Jun. 2009.
7. R. K. Jain, V. R. Barry and G. Harish Kumar Varma, "An Effective Control Strategy for Single-Phase Single-Stage PV Grid-Tied Inverter under Abnormal Grid Conditions," in IEEE Journal of Emerging and Selected Topics in Power Electronics, doi: 10.1109/JESTPE.2023.3321374.
8. J. M. Guerrero, J. C. Vsquez, J. Matas, M. Castilla, L. Garca de Vicua, "Control strategy for flexible microgrid based on parallel line-interactive UPS systems", *IEEE Trans. Ind. Electron.*, vol. 56, no. 3, pp. 726-736, Mar. 2009.
9. H. Zeineldin, E. F. El-Saadany, M. M. A. Salama, "Intentional islanding of distributed generation", *Proc. IEEE Power Eng. Soc. Gen. Meeting*, vol. 2, pp. 1496-1502, 2005.
10. T. Thacker, F. Wang, R. Burgos, and D. Boroyevich, “Islanding detection using a coordinate transformation based phase-locked loop,” in *Proc.IEEE PESC*, 2007, pp. 1151–1156.
11. L. Qin, F. Z. Peng, and I. J. Balaguer, “Islanding control of DG in microgrids,” in *Proc. IEEE 6th IPEMC*, 2009, pp. 450–455.
12. D. N. Gaonkar, G. N. Pillai, R. N. Patel, "Seamless transfer of microturbine generation system operation between grid-connected and islanding modes", *Electr. Power Compon. Syst.*, vol. 37, no. 2, pp. 174-188, Feb. 2009.
13. A. R. Malekpour, A. R. Seifi, M. R. Hesamzadeh, N. Hosseinzadeh, "An optimal load shedding approach for distribution networks with DGs considering capacity deficiency modelling of bulked power supply", *Proc. AUPEC*, pp. 1-7, 2008.
14. H. U. Rehman et al., "Droop control design based on advanced particle swarm optimization for grid-connected multi PV-VSG," The 16th IET International Conference on AC and DC Power Transmission (ACDC 2020), Online Conference, 2020, pp. 2214-2220, doi: 10.1049/icp.2020.0332.