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Enhance Power Quality of Solar PV Energy Generation System with Integrated DG and Grid

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Abstract: This paper examines a multifunctional DS (Distributed Sparse) control technique for a single-stage PV system (SPEGS). When solar irradiation fluctuates, this SPEGS compensates for the nonlinear demand at common connections. SPEGS can multitask. It connects solar PV to the three-phase grid. Reduced harmonics to increase three-phase grid stability. SPEGS includes PV panels, an inverter of voltage sources, a nonlinear load, a three-phase grid, and a DC capacitance are all involved. In the absence of sun irradiation, DSTATCOM (Distribution Static Compensator) may be used (Voltage Source Converter). P&O (Perturb and Observe) maximises PV power extraction. The P&O scheme's tracking capabilities and efficiency under shifting environmental circumstances are also evaluated. Using DS control, it's possible to estimate the reference grid currents' basic component.

Index Terms: Solar PV Power Generation, MPPT, DSA, VSC and Power Quality.

I. INTRODUCTION.

Solar PV (Photovoltaic) generating systems are growing more popular due to rising energy needs, public awareness of climate protection, depleted conventional supplies, and global political and societal challenges related to nuclear power safety [1]. Solar photovoltaic energy generating system (SPEGS) is pollution-free, renewable, and infinite [1-2]. Cost predicts a technology's success or failure. Solar photovoltaic (PV) energy has become a practical and feasible power source due to technology advances.

[3-4] describe SPEGSs' grid involvement. Off-grid and distribution-fed SPEGSs are common. Grid-connected solar PV systems are safer than standalone SPEGS. MPPT (Maximum Power Point Tracking) is required because of the non-linear link between solar PV array voltage and current.

Installing solar PV is costly. Increasing installed capacity helps boost total power.

Literature [7, 8] contains various MPPT designs. P & O (Perturb and Observe) is widely utilised since it is simple [9]. This study uses the P&O approach to collect peak solar energy. Grid-integrated SPEGS takes the most three-phase grid is fed with electricity generated by a PV array. Diverse research groups have suggested alternate control methods [10-11]. These control algorithms maximise SPEGS output and synchronise the grid to feed produced power into a three-phase grid [11]. Optimizing the control algorithm is a common research topic [9-11]. Power electronics-based loads are popular since they're efficient and small [11-14]. Due to harmonics and reactive power, these loads degrade grid quality in addition to increasing distribution losses [12, 13]. Distributed static compensators (DSTATCOM) are used for reactive power compensation, harmonics reduction, load balancing, and power factor change [14].

This device's real-world performance and effectiveness rely on the system's algorithm for control, these gadgets are expensive. Grid-interfaced voltage source converters (VSCs) do all of these tasks efficiently and economically. [15–18] Adaptive controls and neural network-based methods are also discussed. Distributed sparse (DS) control is commonly used to create learning and tracking systems. Standard LMS (Least Mean Fourth) techniques don't employ sparsity, whereas LMF filters do. External signals impact its behaviour. [20-21] offer a distributed adaptive filter as a solution. Before extending the local normalised filter to distributed processing, we add zero norms to increase the estimate constant. An adaptive sparse technique [20-21] is presented to overcome LMF's flaws.

Its most important aspects are as follows.

- Adding a collaboration factor to a normalised adaptive filter enhances estimation [21].

- Zero norms increase convergence and steady-state behaviour in the local adaptive filter.
- The strategy improves transient reactions.
- Use a peer-to-peer architecture that's robust to connection and node failures.

Adaptive distributed control of dual-mode SPEGS with local three-phase grids is at the heart of the proposed research. New approach has two uses. Solar PV electricity may be provided to the three-phase grid and connected loads in first mode if there is adequate sunshine. Using the same system design, it improves power quality in this mode. When there's no sunshine, a DSTATCOM for three-phase grids with the same VSC acts as a DSTATCOM.

This strategy reduces the proposed system's payback period by maximising power electronics.

The suggested method reduces harmonics, improves power factor, balances loads, and achieves unity power factor mode (UPF). MATLAB simulates this control.

II. METHODOLOGY

- **THE PROPOSED SYSTEM'S DESIGN AND CONTROL**

Figure 1 shows a multistage SPEGS.

One converter, a VSC, is all that is needed to maximise the amount of solar power that can be supplied into a three-phase weak distribution network without the need of transformers or inverters. Interface inductors stabilise and maintain distribution network currents. PCI's high pass ripple filter absorbs VSC switching ripple. [14, 23] offer a technique for designing and grading proposed system components. Figure 2 shows a SPEG-connected three-phase distribution network. MPPT switches VSC. The MPPT methodology uses both P&O-based MPPT and adaptive-based VSC control.

A. MPPT Algorithm

[8] Describes MPPT procedures. This study uses P&O to maximise SPEGS [9]. MPPT must create a reference DC link voltage Vdc* from solar panel voltage and array current.

System control is dispersed and sparsely implemented in Fig. 2. grid current (iga, igb), load current (iLa) and the point of interconnection voltage are all examples of PV voltages and currents (VPV, IPV), all considered while applying the suggested control method (vga, vgb). For PCI voltage amplitude,

$$V_t=\sqrt{(2/3(v^2_{ga}+v^2_{gb}+v^2_{gc}))} \text{-------------}(1)$$

All three phase voltages are calculated from line voltages.

$$v_{ga}=\frac{2v_{gab}+v_{gbc}}{3};\ v_{gb}=-\frac{v_{gab}+v_{gbc}}{3};\ v_{gc}=-\frac{v_{gab}-2v_{gbc}}{3} \text{----------------}(2)$$

The in-phase unit templets are computed using phase voltages.

$$U_{pam}=\frac{v_{ga}}{V_t};\ u_{pbm}=\frac{v_{gb}}{V_t};\ u_{pcm}=\frac{v_{gc}}{V_t} \text{-----------------------------------}(3)$$

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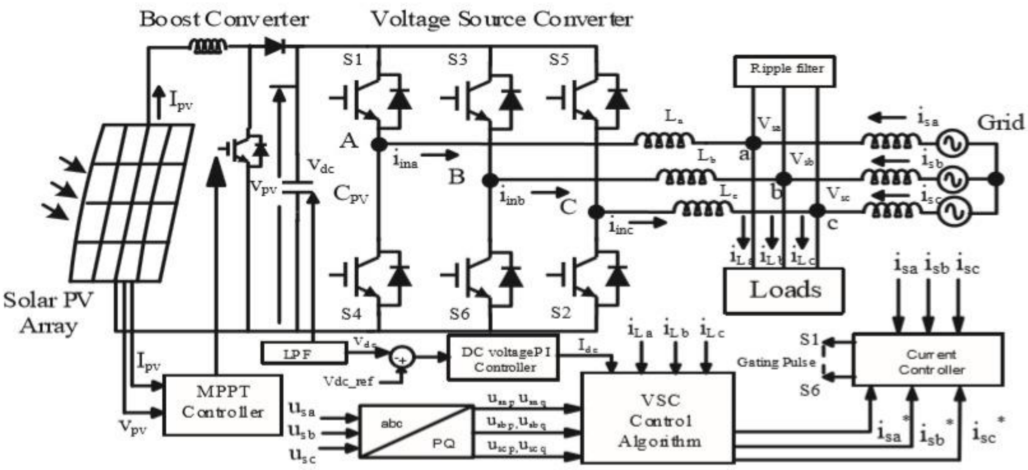

Fig.1: Block diagram of SPEGS

C. Distributed sparse control implementation

Dispersed estimate offers geographical variety [20, 21]. This outperforms a local adaptive filter. This section presents a unique distributed sparse-based control strategy for integrating SPEGS into the grid. Distributed system performance is impacted by node cooperation [21]. Network analysis uses the m node adaptive approach. To compute the Dwpa 0 sparse vector is everyone's goal. Fig. 3 shows neighbourhood nodes (Pm) as a collection of nodes encircling a central node. DWpam(n) and DWlm, a neighbouring node's local estimations, are linked in Node m. (n) [21].

$$\lambda_{pam}(n) = \sum_{l \in p_m} \sigma_{lm} D_{wlm} \quad \text{--------------------}(4)$$

lm is the collaboration weight [19, 20]. In (4), pam (n) substitutes dwpam (n) by merging the observed estimate near m. To obtain an adaptive estimate at node m, Dwlm must be 0. Cooperation consolidates data from several nodes into node m. Fig. 3 shows that each Pm node has a diverse neighbourhood. [20-21] signify a mistake.

$$e_{pam}(n) = i_{La}(n) - \lambda_{pam}(n)^T u_{pam}(n) \quad \text{----------------}(5)$$

For each step, an appropriate update to the basic component of weight for em(n) reduces the error.

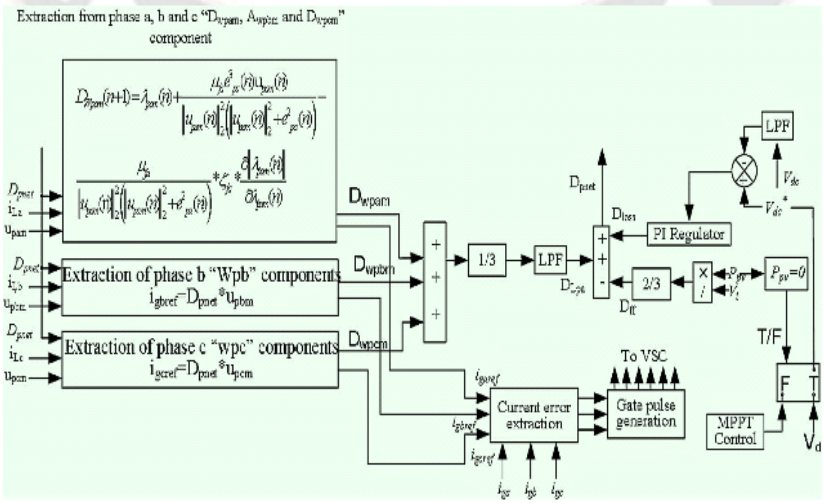

Fig.2: Block diagram for control architecture for SPEGS

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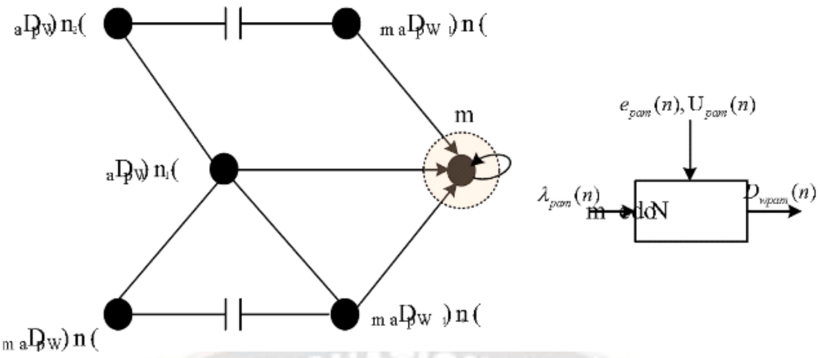

Fig.3: Block Diagram of Distributed Sparse Approach

Battery power. Node m's pam estimation may be used with local data to compute Dwpam (4). Phase 'a''s primary load current component is calculated from the error signal and the cooperation factor pam at node m [19].

$$D_{wpam}(n+1) = \lambda_{pam}(n) + \frac{\mu_{fa} e^{3}_{pa}(n)\, u_{pam}(n)}{\|u_{pam}(n)\|_2^2\left(\|u_{pam}(n)\|_2^2 + e^{2}_{pa}(n)\right)} - \frac{\mu_{fa}}{\|u_{pam}(n)\|_2^2\left(\|u_{pam}(n)\|_2^2 + e^{2}_{pa}(n)\right)} * \zeta_{fa} * \frac{\partial \|\lambda_{pam}(n)\|}{\partial \lambda_{pam}(n)} \text{------}(6)$$

Similarly, the basic weight components of the load currents are computed as follows for phases 'b' and 'c.'

$$D_{wpbm}(n+1) = \lambda_{pbm}(n) + \frac{\mu_{fb} e^{3}_{pb}(n)\, u_{pbm}(n)}{\|u_{pbm}(n)\|_2^2\left(\|u_{pbm}(n)\|_2^2 + e^{2}_{pb}(n)\right)} - \frac{\mu_{fb}}{\|u_{pbm}(n)\|_2^2\left(\|u_{pbm}(n)\|_2^2 + e^{2}_{pb}(n)\right)} * \zeta_{fb} * \frac{\partial \|\lambda_{pbm}(n)\|}{\partial \lambda_{pbm}(n)} \text{------}(7)$$

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$$D_{wpcm}(n+1) = \lambda_{pcm}(n) + \frac{\mu_{fc} e^3_{pc}(n)\, u_{pcm}(n)}{\|u_{pcm}(n)\|^2_2 \left(\|u_{pcm}(n)\|^2_2 + e^2_{pc}(n)\right)} - \frac{\mu_{fc}}{\|u_{pcm}(n)\|^2_2 \left(\|u_{pcm}(n)\|^2_2 + e^2_{pc}(n)\right)} * \zeta_{fc} * \frac{\partial\|\lambda_{pcm}(n)\|}{\partial\lambda_{pcm}(n)} \text{----------------------------------(8)}$$

D. Switching Pulses for VSC

The PI (Proportional-Integral) controller may modify the DC link voltage by comparing the detected (Vdc) and estimated (Vdc*) voltages. Consequently,

$$V_{dc\text{-}error}(n)= V_{dc}*(n)-V_{dc}(n) \text{-------------------(9)}$$

When PPV=0, Vdc* changes to the DSTATCOM reference DC link voltage (Vdc* =Vdc DS*), therefore the PV system runs as DSTATCOM during night or in cloudy conditions (PPV=0). Active power from SPEGS and related loads may be provided to the distribution network utilising just the VSC. PI regulator output is

$$D_{loss}(n+1)= D_{loss}(n)+K_p\{V_{derror}(n+1)-V_{derror}(n)\}+K_I V_{derror}(n+1) \text{ ------------------(10)}$$

Dloss measures active loss. Active power from distribution feeders is employed as an adaptive loss term to sustain DC-link voltage self-healing during VSC switching (Dloss). A feed-forward term is estimated to optimise PV system performance under different climatic conditions.

$$D_{ff} = \frac{2P_{pv}}{3V_t} \text{ ---------------------(11)}$$

PCI voltage amplitude Vt (1). According to DPnet, the grid's active power is

$$D_{pnet}=D_{Lpa}+ D_{loss}-D_{ff} \text{ -------------------(12)}$$

Identify the corresponding average load component of all three phases to balance load.

$$D_{Lpa}=\frac{\left(D_{wpam}+ D_{wpbm}+D_{wpc}\right)}{3} \text{ ----------------------------(13)}$$

The local distribution network's reference currents are also calculated:

$$I_{garef}=D_{Lpa}*u_{pam};i_{gbref}=D_{Lpa}*u_{pbm};i_{gcref}=D_{Lpa}*u_{pcm} \text{-------------------(14)}$$

Using hysteresis controllers, indirect current control creates VSC switching pulses. Following hysteresis controller errors are estimated:

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$I_{ga\_error}=i_{ga}- i_{garef}$; $i_{gb\_error}= i_{gb}-i_{gbref}$; $i_{gc\_error}=i_{gc}-i_{gcref}$--------------------- (15)

III. RESULTS AND DISCUSSION

PV simulator has nonlinear loads, Hall-Effect sensors, VSC, and R-C filters. In the absence of PV array active energy feeding is investigated under various testing conditions, such as the wheeling of active power to the load in nominal condition, the load perturbation condition, and different environmental circumstances. SPEGS is a DSTATCOM with a similar VSC and its basic features for this purpose. Real-time DS is used by the DSP-dSPACE controller.

A. Response under Nonlinear Balanced Loading

Balanced nonlinear load SPEGS behaviour.

Voltages and currents are in phase, sinusoidal, and approximately equal in amplitude on a three-phase grid. Equal angles divide grid voltages and grid currents, representing their balance as a vector. Voltage and current harmonic distortion (vgabc) are within IEEE 519-standard range. Grid voltages and currents influence power factor and quality (PQ). Three-phase voltages and currents with identical magnitudes (g). Three-phase electricity and voltage (h). Unused PV power is delivered through VSC to the building's distribution feeder. Phase 'a' grid voltage and load current. There are balanced, sinusoidal, and near-unity PF grid voltages and currents. All grid voltage and current THD readings are within IEEE-519 limits [22], confirming system health.

B. Results from Experiments with Nonlinear Loads

Unbalanced nonlinear load on the suggested system. Three-phase grid currents (vgabc) (igabc). Electrical signals in three-phase systems feature sinusoidal waves with almost similar frequencies. Is there a better way to distribute? The three-phase voltages, currents, and grid power may be seen here. (c) shows balanced grid voltages and currents (vgabc) (igabc). Voltages and THD currents are displayed (igabc). iga's THD up to the 50th harmonic is within IEEE standard-519's allowed range. Vgabc and VSC currents are (ivsc). Three-phase voltages, VSC currents, PF, and PQ are provided (Power Quality). Three-phase balanced voltage and VSC current vector diagrams demonstrate equal grid voltage angles. Vgabc with load currents (igabc).

(j) Displays three-phase voltages, loads, PF, and PQ. Semi-square voltages and load currents in a three-phase vector diagram.

Multifunctional VSC delivers collected energy to utility and load. Voltages and currents in phase 'a' After a regressive analysis, grid voltages and currents are balanced, sinusoidal, and near unity. IEEE-519 specifies a THD level for voltages and currents [22].

C. DS Control Approach Behaviour

Several intermediary indications indicate the DS approach's behaviour. Product of phase 'unit template and error cube, upa*DWpam and error cube (epam). To show the influence of the constant, (pa) basic (iLa, DLpa, Dloss), weight for active loss (Dloss), and net active component (wca) of load current with co-operation (pam) are shown (Dpnet). As the load is increased, the average component rises and all intermediate signals reach steady-state. Performance when loads are suddenly eliminated. When phase 'a' is unloaded, all intermediate signals and load currents revert to steady-state, suggesting that SPEGS' dynamic performance is quick and adequate. After disconnecting the load from phase 'a,' the load current (iLa) immediately drops to zero and all other signals attain steady-state.

D. Solar PV Energy Generation System Dynamic Behavior

SPEGS's response to a nonlinear load disturbance depicts a fast load rise. Load current (iLa), feed-forward term weight Dff, reference grid current (igrefa), and sensing grid current (iga) waveforms (ipv).

Load increase decreases reference grid current, which decreases observed grid current. All signals have attained steady-state at this stage. System performance drops when loads are abruptly eliminated.

Due to added electricity, reference grid currents increase, followed by measured grid currents.

E. Dynamic Performance at Varying Climatic Condition

The 1000 W/m2 to 500 W/m2 shows system behaviour. This research found that when sun irradiation falls, DC connection voltage remains constant.

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Grid current amplitude falls but remains sinusoidal. PV insolation increases from 500 to 1000 W/m2. The quantity of energy transmitted to the distribution network grows with insolation. DC link voltage and grid currents are maintained. The feed-forward term is calculated based on the control output. Fig 4 exhibit 100% MPPT at 1000 and 500 W/m2.

F. DSTATCOM Performance of the Computer System

As a DSTATCOM with a comparable VSC, this system can provide active solar PV power into the distribution network when the sun isn't shining. PV power is recovered when there is no sunshine, whereas SPEGS reacts dynamically. Absence of PV power (Vdc=Vmp to Vocn) causes compensating currents (ivsc). DSTATCOM allows grid self-healing. DC link voltage is maintained while the phase of the distribution grid currents is inverted and reduced. After a few cycles, these grid currents begin to revert to their original state. After the solar PV electricity was restored, the performance was better.

G. Comparison of the DS Control Approaches with the Existing DS Control Methods.

Validates the technique. SPEGS load disconnection occurs at 4s. LMS and LMF are the primary weight components of distributed sparse-based control. The recommended control technique outperforms ILST and PLL-Less. In imbalanced loads and rapidly changing environmental circumstances, the recommended control technique converges quicker than LMS, PLL-Less, and FZANLMF, according to the findings. According to these statistics, DS (Distributed Sparse)-based control gives excellent efficiency in weight calculation. According to this research, the recommended approach has lower mean square error (MSE) than existing controls in each key examined case and in typical operating conditions. The originality of this strategy is node m's near neighbours, including node m. In error estimation (5), each node m combines peer nodes' prior estimations into its own. Estimate is dependable and smart because [20, 21].

The recommended control is most successful with a weak distribution system [9, 24 and 25]. In the absence of solar power, this system with the recommended control approach acts as a DSTATCOM, unlike ILST [24], LMS [25], and LMF [9].

Under voltage sag and swell, the grid current is boosted and dropped to maintain a sinusoidal power supply. Voltage changes don't affect PV voltage, current, or output power greatly.

A. Simulation Results:

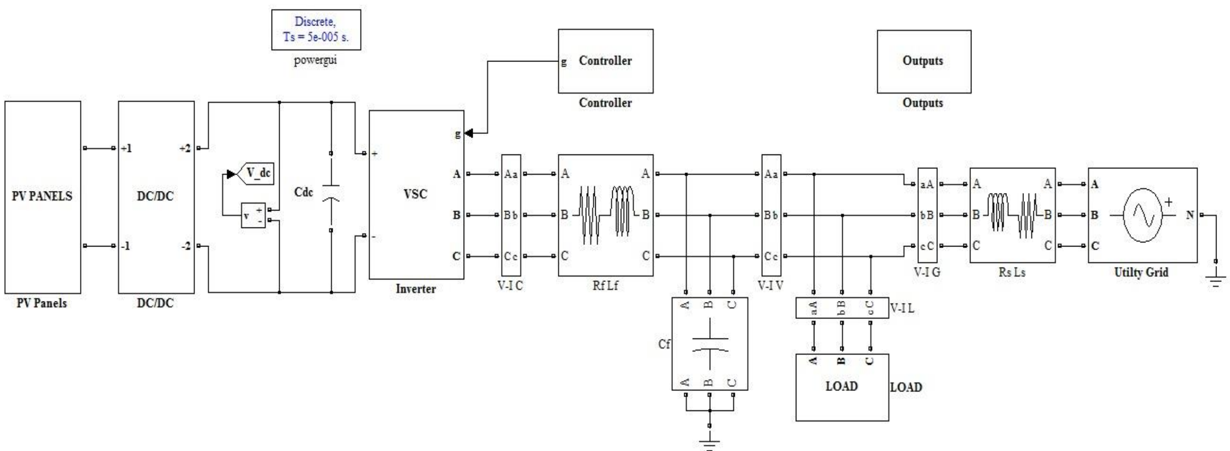

Fig.4: Balanced Nonlinear loading

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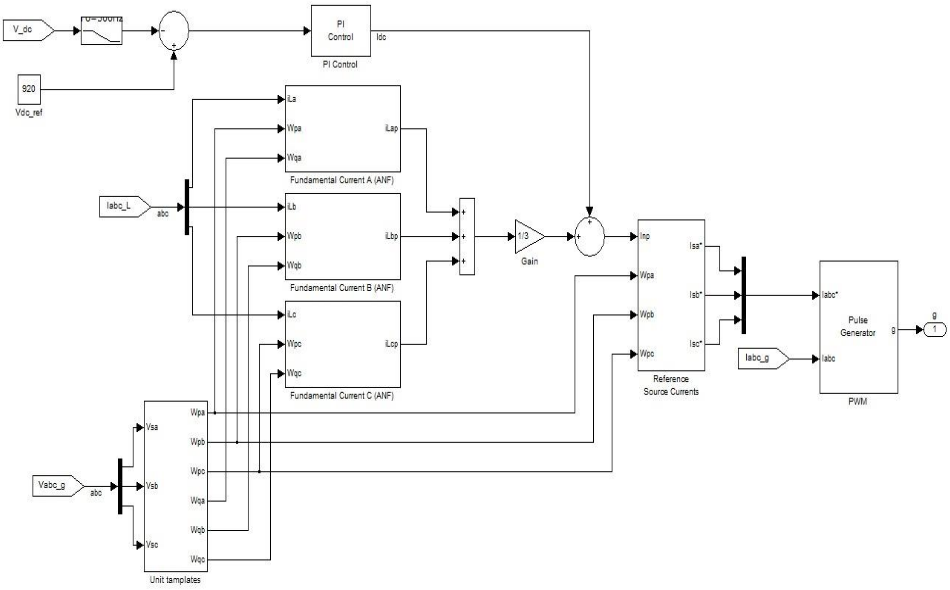

Fig.5: Unbalanced Nonlinear loading

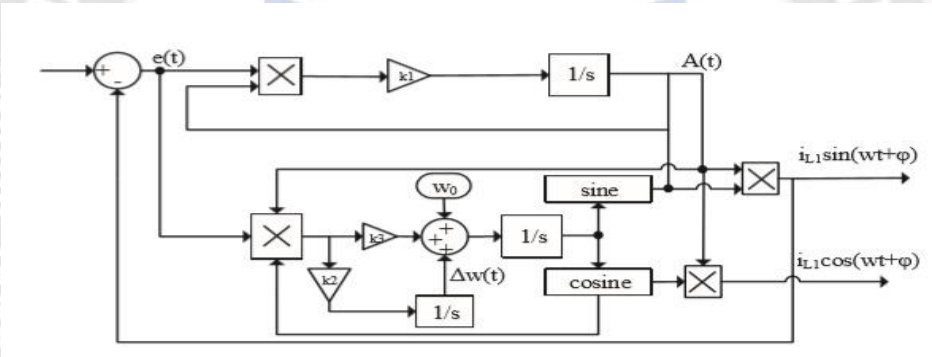

Fig 6: Controller

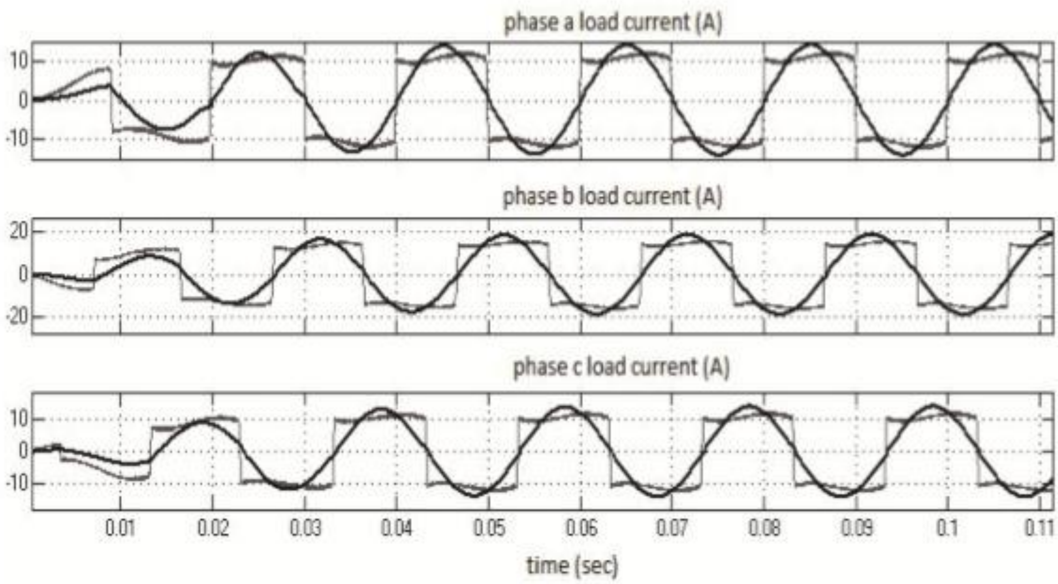

Fig 7: Phase a, b, c Load Currents (A)

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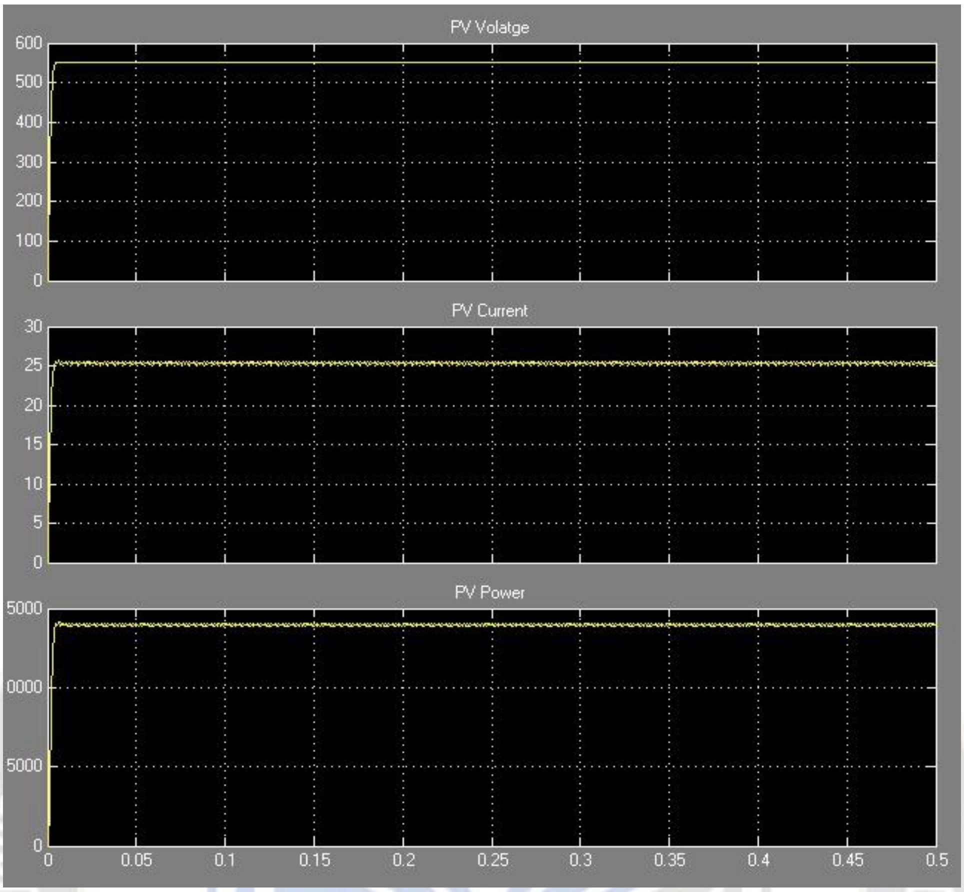

Fig.8: PV Voltage, PV Current, PV Power

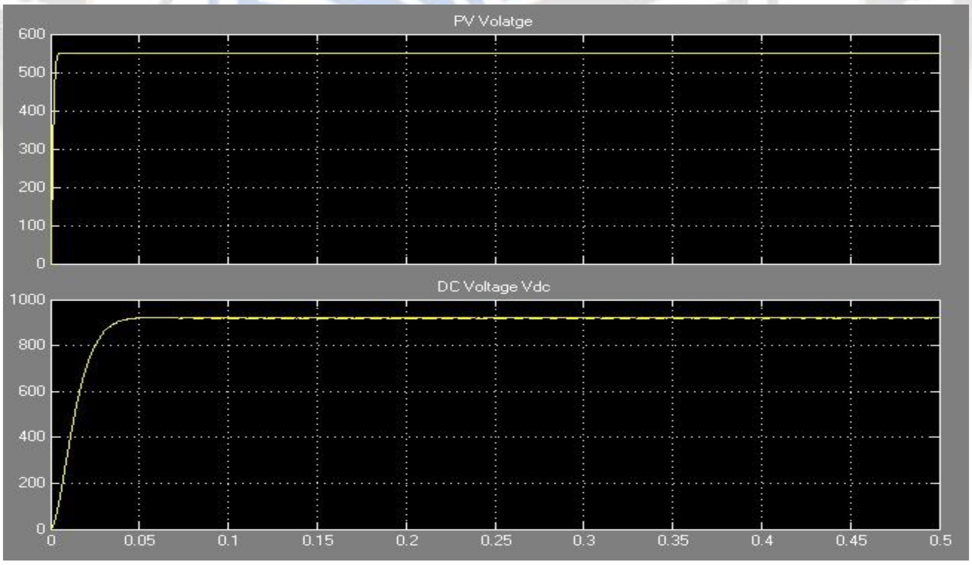

Fig.9: PV Voltage , DC Voltage [Vdc]

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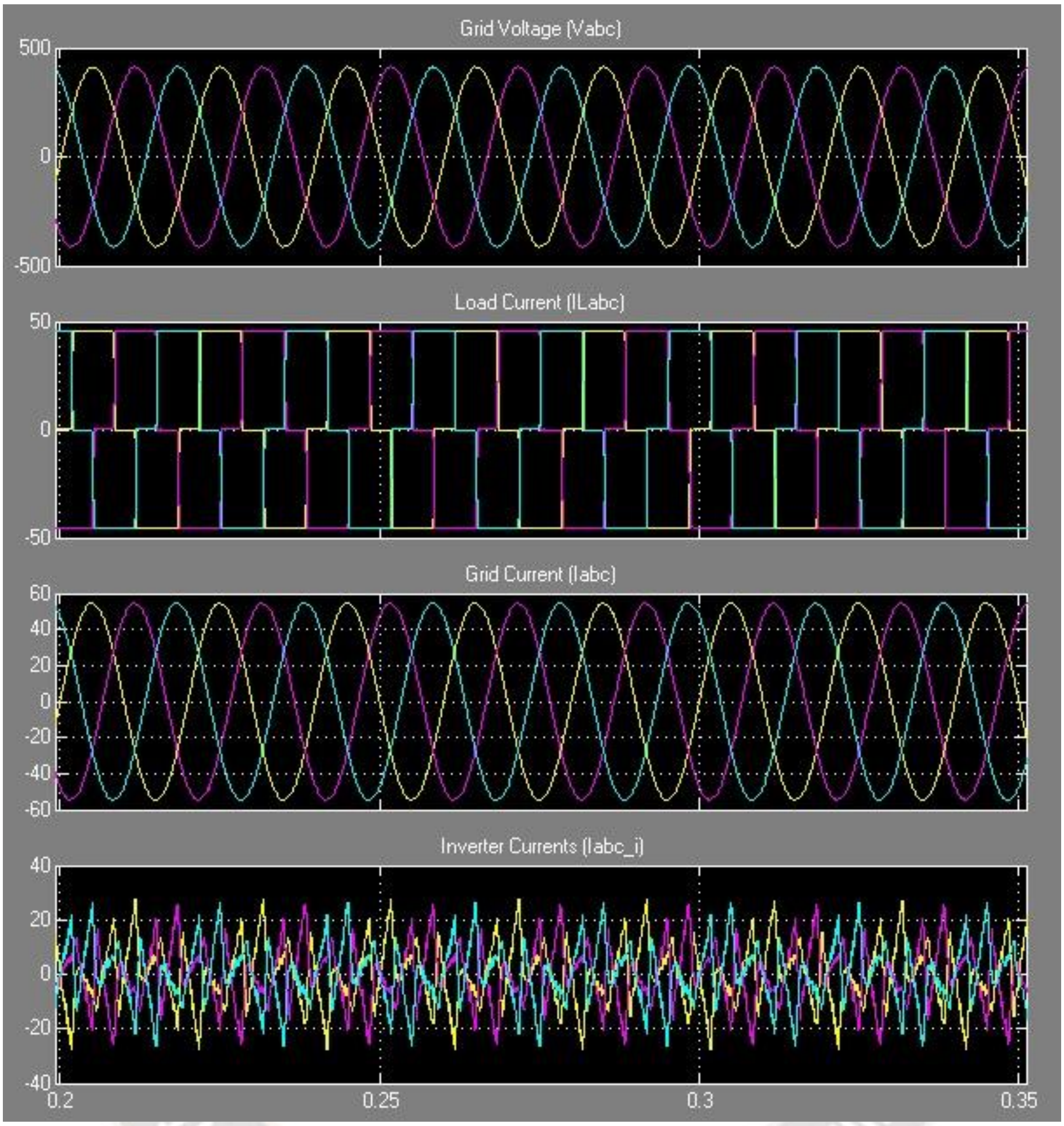

Fig.10: Grid Voltage [Vabc] & Load Current [ILabc], Grid Current[Iabc], Inverter Current[Iabc_i]

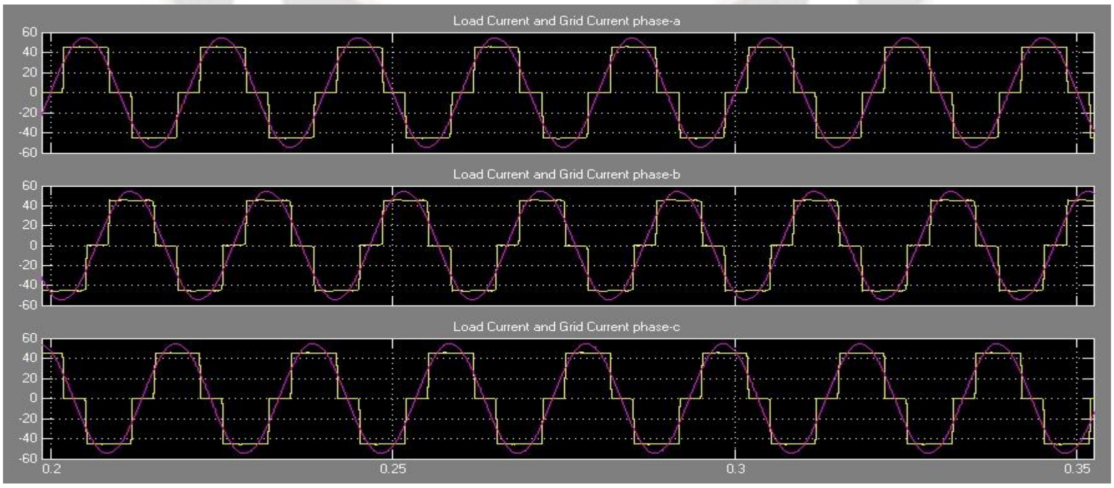

Fig.11: Load Current and Grid Current Phase-a, Phase-b and Phase-c

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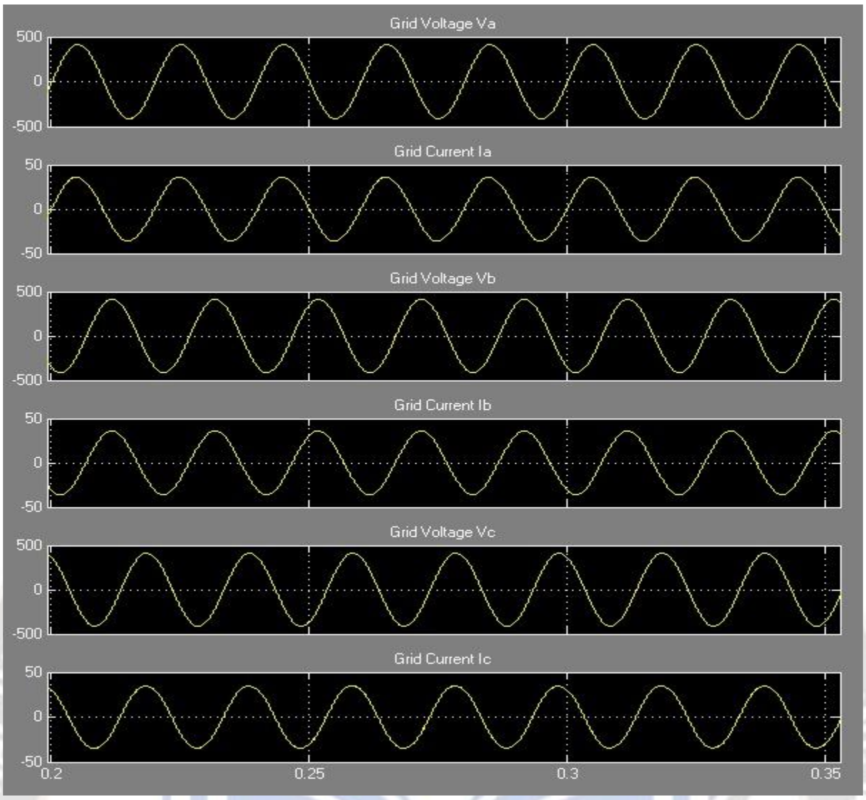

Fig.12: Grid Voltage [Va], [Vb], [Vc], Grid Current[Ia], [Ib], [Ic].

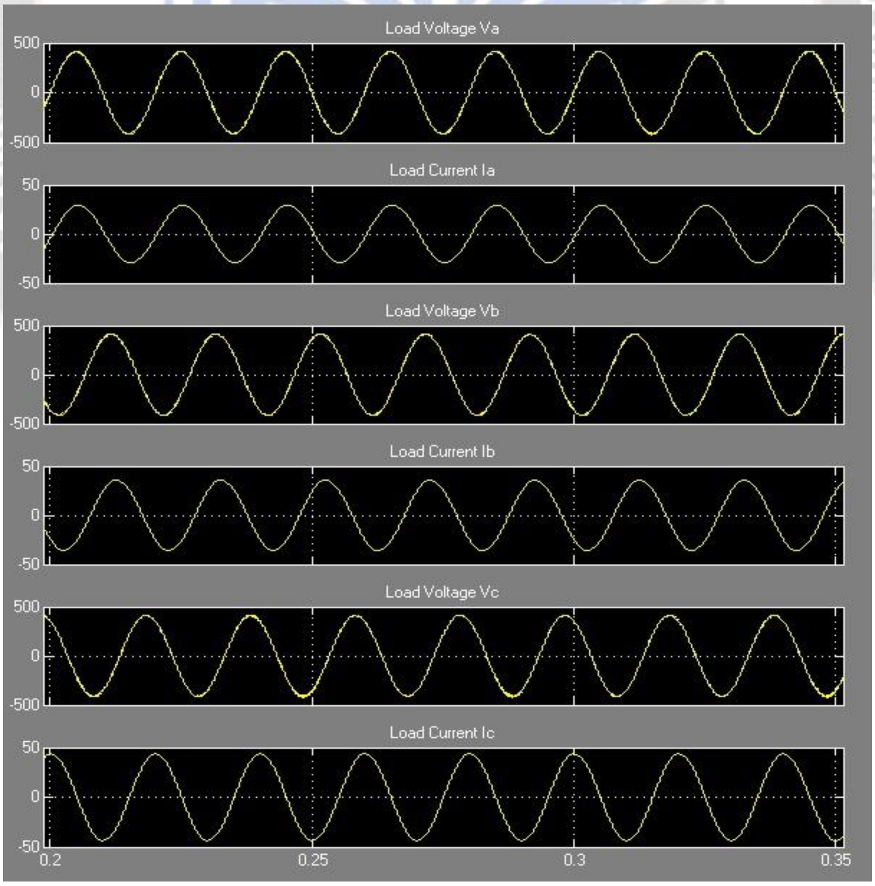

Fig.13: Load Voltage Va, Vb, Vc and Load Current Ia, Ib, Ic.

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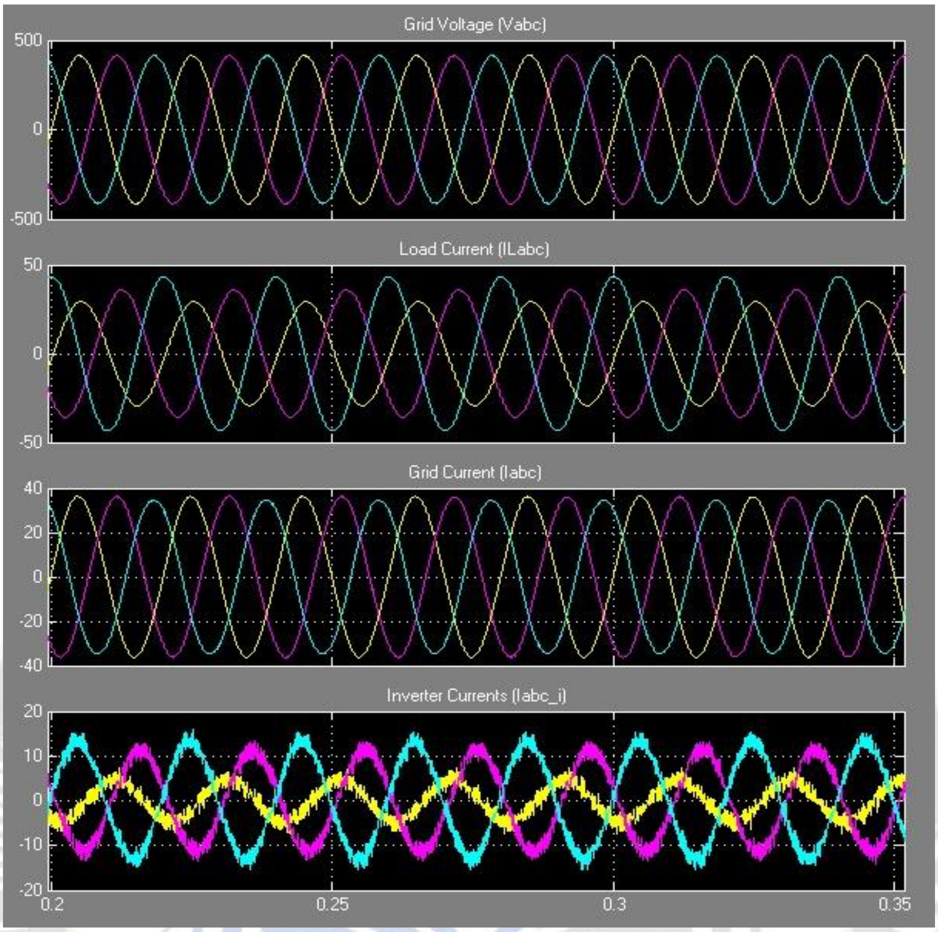

Fig14: Grid Voltage[Vabc], Load Current[ILabc], Grid Current [Iabc], Inverter Current[Iabc_i]

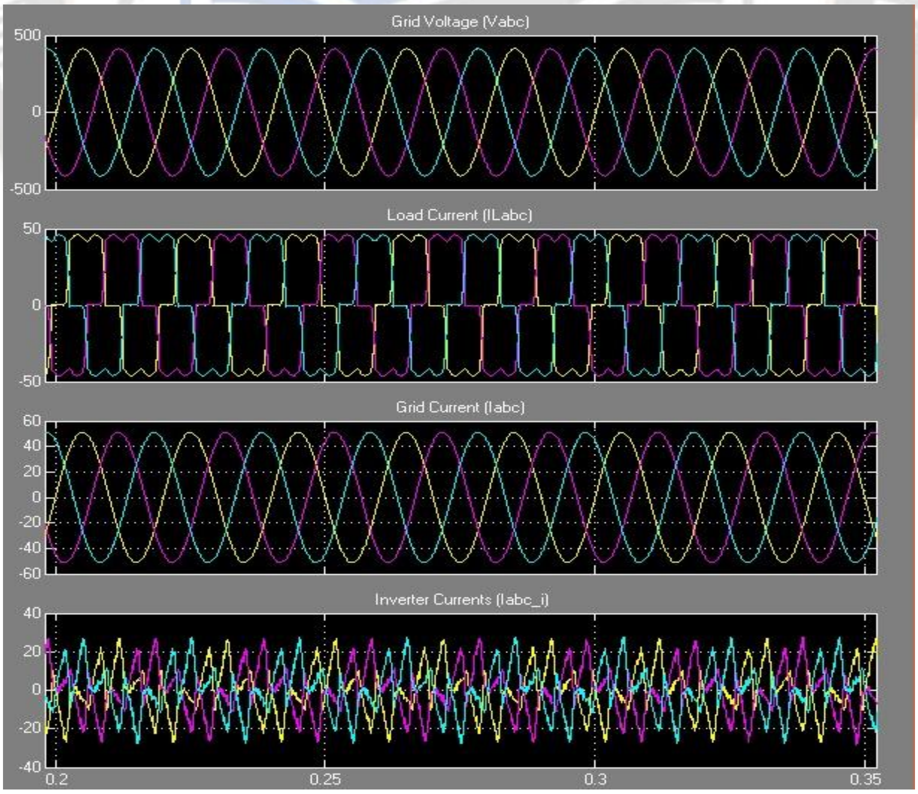

Fig 15: Grid Voltage[Vabc], Load Current[ILabc], Grid Current[Iabc], Inverter Current[Iabc_i]

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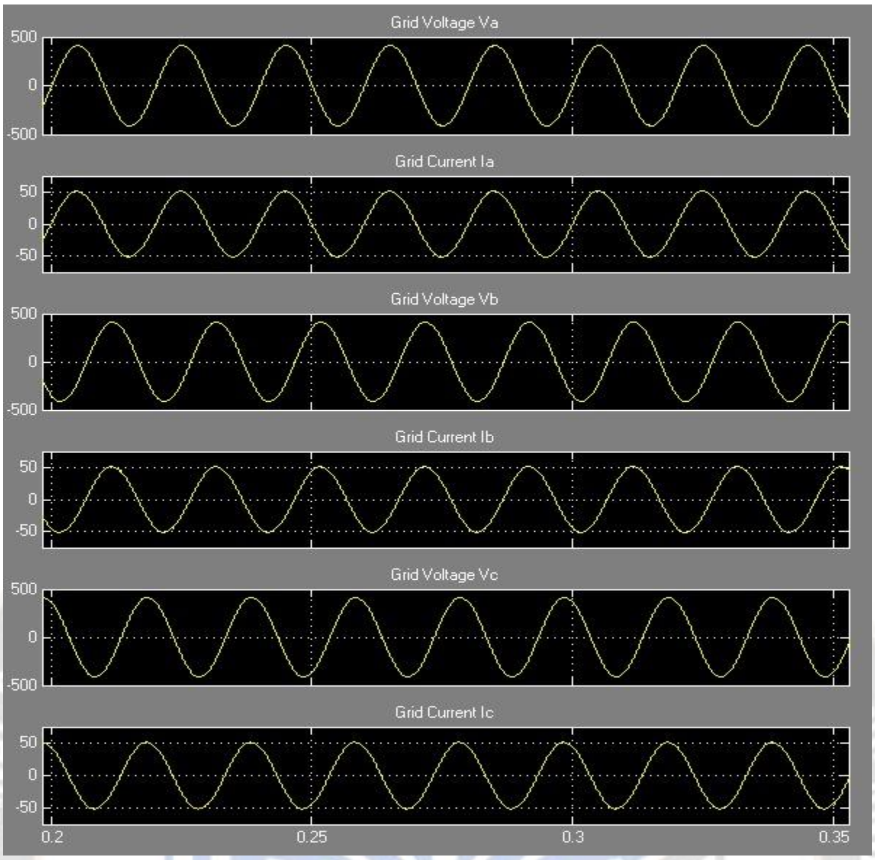

Fig 16: Grid Voltage Va, Vb, Vc, Grid Current Ia, Ib, Ic.

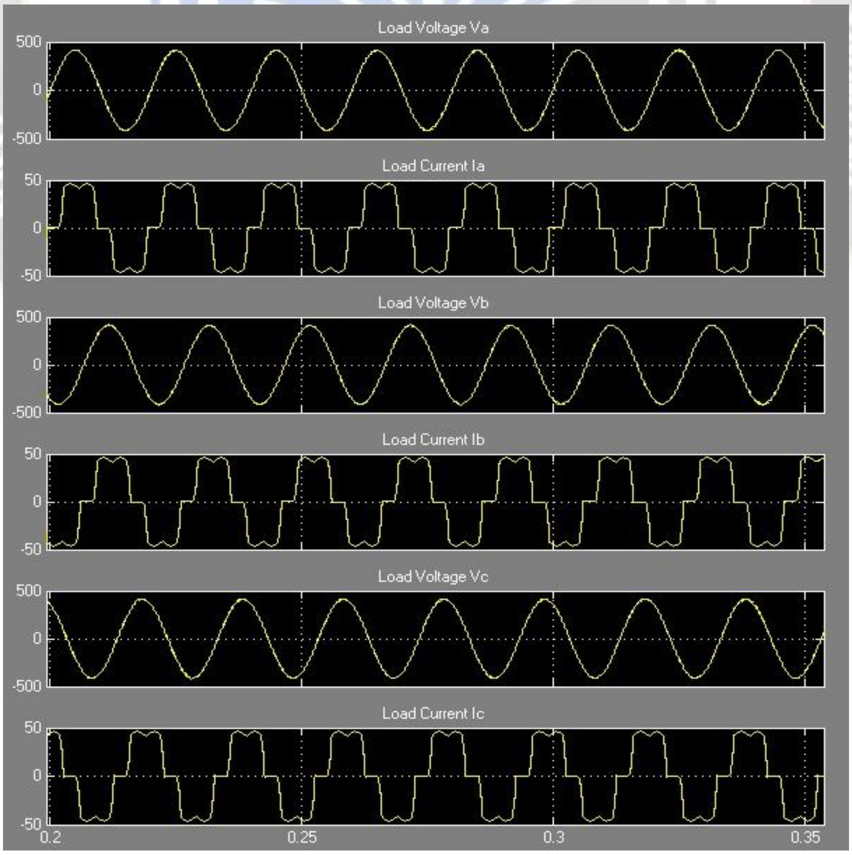

Fig 17: Load Voltage Va, Vb, Vc and Load Current Ia, Ib, Ic

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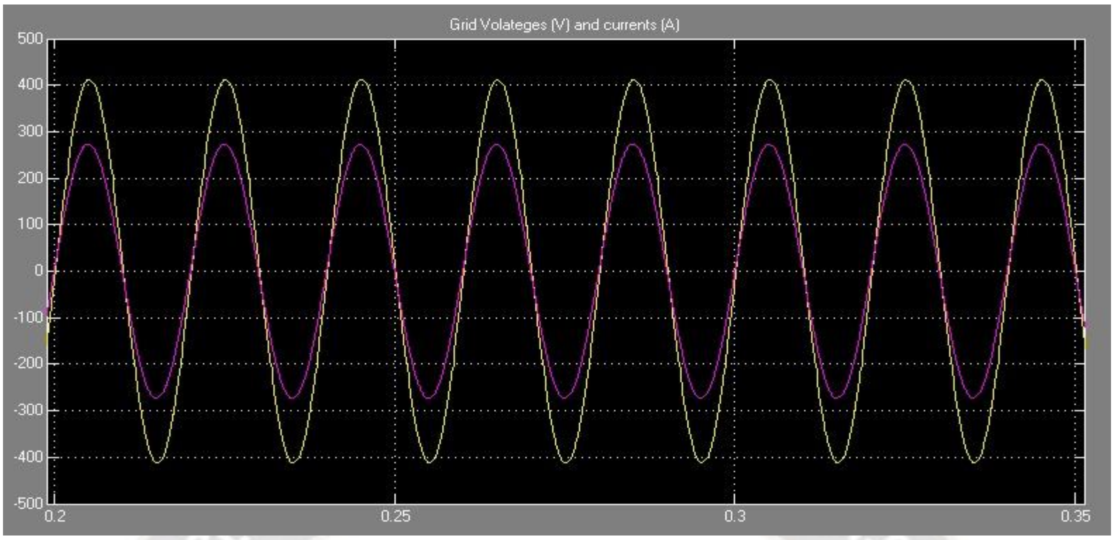

Fig 18: Grid Voltage [v] and Current[A]

IV. CONCLUSION

In order to improve power quality, single-stage SPEGS with a distribution feeder is now available. Distributed sparse method has a simple and sturdy design, which are its most important features. Nonlinear load, imbalanced load, the presence and absence of sun rays, and variable insolation levels are all evaluated using the suggested system. An adaptive sparse control strategy seems to be the best method for extracting the active load current component of multimode SPEGS from experimental findings. The suggested control method's dynamic behaviour has been found to be superior to that of current control methods. At unity power factor operation, the suggested method has worked successfully in all cases, and it has solved grid power quality issues. The IEEE-519 standard limits the THD of grid currents [22]. The prime intent of a DG is to associate the 0.5Kw power generation. This DG power and grid simultaneously work together to reach the power offer by the load when solar power generation varies and enhance the power quality of the overall integrated renewable energy sources.

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