Photovoltaic Powered Transformer less Hybrid Converter with Active Filter for Harmonic and Reactive Power Compensation

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ABSTRACT

This paper proposed a Transformer less Hybrid SEries Active Filter (THSeAF) that upgrade the power quality in single-stage frameworks with steady renewable Photo Voltaic (PV) supply. It strengthens basic loads and carrying on as high-consonant impedance that does not below the critical loads, it cleans power system and guarantees the utilization of Unity Power Factor (UPF). In this article, manages energy management and power quality issues identified with electric transportation and concentrate on enhancing the electric vehicle load connected to grid. This depends on the Power Factor Correction (PFC) change with harmonic modulation technique that will give advancement of power factor in PFC operation. The control technique was intended to anticipation of current harmonic distortions with the nonlinear loads to control the flow of utility with no standard massive and expensive transformer. Power factor alongside AC side will likewise kept up to some esteem and furthermore dispense with the voltage distortions at the Common coupling point. Here we protecting sensitive loads from voltage twists, swells and sags as for control framework, without the arrangement transformer it is worthwhile for a modern usage. This article was done with 2-kVA control showing the adequacy of the current topology. Further, in this paper implementation of incremental conductance based maximum power extraction techniques utilized PV panel. The main difference from exist tracking system includes elimination of PI controller. The resultant method is capable of tracking possible power extraction rapidly and accurately in steady state and dynamic period. The result indicates the feasibility and improved functionality of the proposed schemes.

Keywords: Power factor correction(PFC), Dynamic voltage restore(DVR), Transformerless hybrid series active filter(THSeAF), Series active filter(SeAF), Source current harmonics, Voltage distortion, power quality improvement, Photovoltaic.

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1. INTRODUCTION

The forecast of future smart grid related with electric vehicles charging stations leads genuine worries for power quality in power distribution system. The harmonics produced by non-direct loads (electric vehicle batteries) in reality greatly affect the system which impacts the hardware ought to be considered in modern grid. The raised current contorts warmth, losses, and causes failure of equipment's. This phenomenon must be dispensed with, which diminishes the proficiency of the system [1].

To prevent voltage distortion at the point of common coupling PCC, Dynamic Voltage Restorer is advised. Another way to protect the system is to directly reduce the pollution of power electronics based loads at their source. There are other attempts to protect the plant. There exist two active devices to overcome described power quality issues [2]. The first category is series active filter Series Active Filter (SeAF) including hybrid, can reduce current harmonics fed from non-linear loads. Shunt active filters are well known compared to series active filters. But there is a great advantage of series active filters that is low level compensators can be used. Howe ever, the complexion configuration and necessity of isolation of series transformer makes in an industrial application [3]. The second category is to compensate voltage issues. A Dynamic Voltage Restore (DVR) is same as SeAF. These two categories are different from each other in control principles. The difference depends on the purpose of the system.

The benefit of the proposed system is it can remunerate the harmonic voltage and current produced by non-linear loads [4]. Transformer less Hybrid Series Active Filter is a substitute choice to the conventional power exchanging converters, where each stage can be controlled and worked without disturbing different phases [5]. This paper shows that the partition of three phase converter to a solitary stage H-bridge converter has permitted the elimination of transformer cost by detaching transformer and empowers modern application for filtering purposes. The setup has indicated incredible viability in the requested execution in solving the issues of current and voltage distortions, Power Factor (PF) on load terminals. The general piece outline as appeared in Fig.1. In this article contributions are made in numerous ways of the whole structure, including inverter design, PV panel

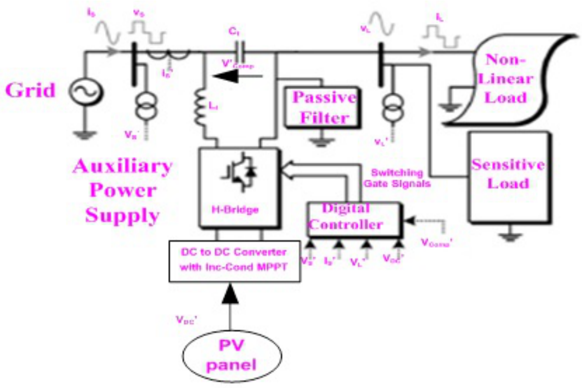


Fig.1: *Proposed Electrical diagram of the THSeAF in a single phase utility.*

Table 1: *Configuration parameters of source and auxiliary source.*

Symbol	Definition	Value
v_s	Line phase-to-neutral voltage	120 Vrms
F	System frequency	60 Hz
Lf	Switching ripple filter inductance	5 mH
Cf	Switching ripple filter inductance	2 μH
G	Control gain for current harmonics	8Ω
V_{DC_ref*}	VSI DC bus voltage of the THSeAF	70 V
PI_G	Proportional gain (K_p), integral gain (K)	0.025(4*) 10(10*)

Table 2: *Load Side Configuration parameter.*

Symbol	Definition	Value
$R_{nonlinearlode}$	Load resistance	11.5Ω
$L_{nonlinearlode}$	Load inductance	20 mH
P_L	Linear load power	1 KVA
PF	Linear load power factor	46 %
T_s	dSPACE Synchronous sampling time	40 μH
f_{PWM}	PWM frequency	5 kHz
V_{DC_ref*}	VSI DC bus voltage of the THSeAF	70 V

selection, incremental conductance programming, simulation setup and analysis of grid integration.

2. PROPOSED THSEAF

The Transformer less Hybrid Series Active Filter (THSeAF) consists of an H-bridge converter connected in series between source and load. A shunt passive filter provides a low impedance for current

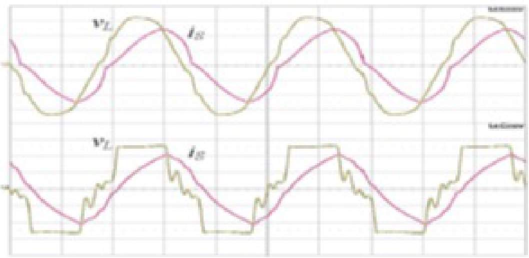


Fig.2: *Regular operation and grid's voltage distortion*[1]*.*

harmonics [6]. A DC auxiliary source is connected to inject voltage during voltage sags. This grid is developed for a 2.2 KVA rated power. The proposed system parameters are shown in a Table.1 and Table.2. A source of 120Vrms is connected to 1.1KVA nonlinear load, 998VA linear load and 0.46PF [7]. The THSeAF is connected in series to inject the voltage during the time of distortion. On DC side the compensator (H-bridge) auxiliary source is connected. HSeAF is mostly used for compensating distortions in current type of non-linear loads. For example the distorted voltage and current harmonics are shown in Fig.2 during regular operation and when distortion is occurred due to non-linear loads.

This proposed setup can directly interface with the grid with isolating the cumbersome transformer makes the topology equipped for controlling current harmonics, voltage distortion at the point of common coupling PCC [8]. Regardless of the possibility that the quantity of switches are increased in the system. This THSeAF extremely successful and less exorbitant contrasted with any arrangement compensators, which need to associate the transformer to infuse voltage into the power grid to compensate voltage distortion [9]. The passive filters comprise of high pass filter [10]. The upsides of proposed topology over existing are plainly expressed. Estimation of production in financial is 45% reduction in components cost and also reduction in assembly terms.

2.1 Equivalent circuit configuration for current harmonics

The THSeAF acts as a VSI. To prevent the source from current harmonics which drift from the nonlinear load, SeAF should provide low impedance for fundamental components and high impedance for all harmonics as indicated in Fig.3

The passive filter is obligatory to compensate current issues and voltage distortion and to keep up adjusted voltages at load terminal. The execution of a SeAF for a current control is considered from Fig.3 of phasor equivalent circuit. The non-linear load is nothing but a resistance representing active power and created harmonic current impedance represent nonlinear load. If source current is free from har-

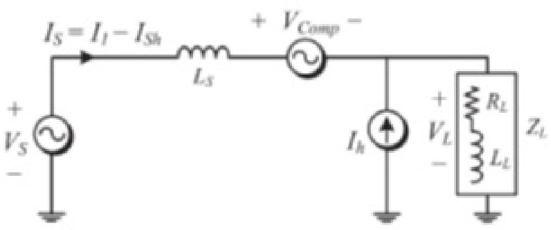


Fig.3: *THSeAF equivalent circuit for current harmonics*[1].

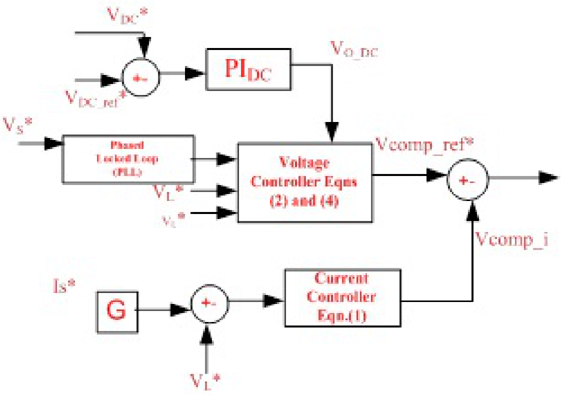


Fig.4: *control system scheme of the active part.*

monics that will enhance the voltage distortion at the grid. The THSeAF goes about as low impedance for harmonics and passive filters acts as low impedance for all harmonics and open circuit for fundamental. This additionally enhances power factor.

2.2 Control schemes of THSeAF and Proportional Integral

A DC auxiliary is connected to get a balanced supply at the load terminals. During the time of sags and swell DC auxiliary is used to inject or absorb power to keep the voltage magnitude at a particular limit at the load terminal. But still, if the compensation of voltage sag and swell is less imperative, a capacitor can be installed. Then, the DC link voltage across the capacitor will regulate as shown in Fig.4 The compensating voltage for current harmonic benefit is obtained as following equation.(1)

$$I_{PV} = N_P.I_{PH} - N_P.I_o\left[e\left(\frac{q\left(V_{PV}+R_SI_{PV}\right)}{AKTN_S}-1\right) - Np\frac{(V_{PV}+R_S.I_{PV})}{R_{SH}.N_S}\right] \quad (1)$$

Hereby, as voltage alteration at the load terminals is not anticipated, the voltage swell and sag should also be examined in the inner-loop. The complete

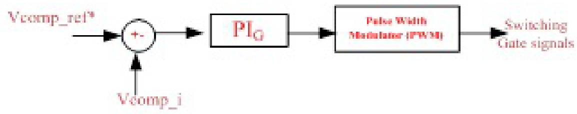


Fig.5: *Block diagram of THSeAF and PL controller.*

closed loop equation (2) permits to indirectly keep the voltage magnitude at load side equivalent to VL* as a predefined value, within satisfactory margins.

$$V_{\text{comp\_v}} = V_L' - V_L' \sin(\omega_s t) \quad (2)$$

An outer loop controller is used where a capacitor can replace an DC auxiliary source. An inner loop control strategy is indirect control principle. Gain represents as the impedance for current harmonics in a suitable level to clean the grid from harmonics which are fed from non-linear loads.

The second Proportional Integral (PI) controller in the outer loop is to enhance the effectiveness when regulating the DC bus. Thus, more accurate and faster response will be achieved without compromising the compression performance of the system. The gain should be kept in such a way that the current harmonics are prevented from flowing into the grid. As discussed for more accurate compensation of current harmonics, the voltage harmonics must be taken into consideration. The compensation of voltage is done to compensate the current harmonics is shown in Fig.5 The compensating voltage for current harmonic benefit is obtained as following equation.(1) The voltage distortions are not desired at the load terminals, the voltage sags and swell are investigated in the inner loop. The closed loop equations help us to indirectly maintain voltage magnitude at load side must be equal to (VL) within a specified limit.

The complete control scheme of the proposed system THSeAF is shown in Fig.1 is implemented in MATLAB/ Simulink for real time simulations and calculation of the compensating voltage, the source voltage and load voltage along with the source current is given as the input signal to the system indirect control increases the stability of the system. The difference between the source current and fundamental components gives the source current harmonics.

The source current harmonics are attained by extracting the important component from the source current.

$$V^*_{comp\_ref} = V_{comp\_v} - V_{comp\_i} + V_{DC\_ref} \quad (3)$$

Where Vdc reference is the voltage required to maintain the dc bus voltage constant.

$$V_{DC\_ref(t)} = V_{o\_DC}.Sin\left(\omega_s t\right) \quad (4)$$

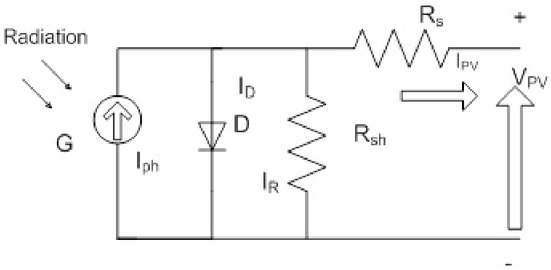


Fig. 6: *Equivalent circuit model of solar cell.*

A phase locked loop PLL is used to get the reference angular frequency. The current harmonics contain fundamental components are similar to the source voltage in order to correct the power factor. This current represents the reactive power of the load. Gain acts as resistance to the harmonics and converts current into a reactive voltage. The voltage which is generated from the loop will clean the source current from harmonics. After that, a reference signal is compared with the measured output voltage and applied to the PI controller to generate gate signals.

2.3 Modelling of PV modules

The modelling of photovoltaic array panel can be applied from the mathematical classical in Eq.(5), which is consequent from the cell equivalent circuit where every cells are identical [11][12].

$$V_{comp\_i}(t) = (-Gi'_s + V'_L) - [\lfloor -Gi_{S1} + v_{L1} \rfloor \sin(\omega_s t - \theta)] \quad (5)$$

Where I_{pv} is the photovoltaic panel current, V_{pv} is the PV output voltage, RS is the cell series resistance, q is the electron charge in 1.6×10^{-19} C, Rsh is the cell parallel resistance, Iph is the light produced current , k is the Boltzmann constant generally 1.38×10^{-23} J/K, A is dimensionless factor, IO is the reverse saturation, T is the temperature in K, NS and NP represent number of cells jointed in series and parallel respectively. Generally, every PV cell is basically formed as a P-N junction. It converts sunlight energy into electrical energy without any interrupt of the environmental issues. The Equivalent mathematical model of PV system is shown Fig.6

The system consists of a photovoltaic direct current source with grid connecting to loads at the transformerless hybrid inverter. The photovoltaic are demonstrated as nonlinear voltage sources. These sources are associated with DC-DC converters which are coupled at the DC side of a DC/AC inverter. The DC/DC associated with the photovoltaic array operates as a Maximum power point tracking (MPPT) controller. Numerous MPPT calculations have been proposed in the writing, for example, Constant Voltage (CV), Incremental Conductance (Inc-Cond), Perturbation and Observation (P&O). The P&O technique has been broadly utilized in view of its basic and simple feedback structure and less measured parameters [13]. The P&O calculation with control input control [14]-[20] is appeared in Fig.7. As PV current and voltage are resolved, the power is computed. At the most extreme power point, the derivative (dP/dV) is equivalent to zero[15][16]. The most extreme power point can be accomplished by changing the reference voltage by the measure of ΔVref.

There is an expansive number of tracking algorithm technique that can track Maximum Power Points (MPPs)[17]. Some of them are simple and basic, for example, those in view of current and voltage feedback, and some are more confounded, for example, perturbation and observation (P&O) or the incremental conductance (Inc-Cond) strategy. They additionally fluctuate in many-sided quality, sensor prerequisite, speed of convergence, cost, scope of operation, ubiquity, capacity to distinguish numerous nearby maxima, and their applications [18]-[19].

Having an inquisitive take a gander at the suggested strategies, hill-climbing and P&O are the methods that were in the focal point of consideration due to their effortlessness and simplicity of execution. Hill-climbing [20] is perturbation in the duty ratio of the power converter, and the P&O technique [15] is perturbation in the working voltage of the photovoltaic array. In any case, the P&O calculation can't contrast the array terminal voltage and the actual or genuine MPP voltage, since the adjustment in power is just considered to be a consequence of the array terminal voltage perturbation. Accordingly, they are not sufficiently precise they perform steady state fluctuation, which subsequently squander the energy [8]. By limiting the perturbation step size, fluctuation can be decreased, yet a littler perturbation size slows down the speed of tracing MPPs. Consequently, there are a few disservices with these techniques, where they fail under quickly changing climatic conditions [19].

On the other side, some MPPTs are more fast and exact and, accordingly, more great, which require exceptional design and familiarity with particular subjects, for example, fuzzy logic [20] or neural network system strategies. MPPT FLC controllers have great execution under shifting climatic conditions and show preferable execution over the P&O control strategy [8]; nonetheless, the fundamental weakness of this technique is that its viability is deeply dependent on the subject to the specialized learning of the architect in registering the error and coming up the rule-based table. It is incredibly dependent to how a designer organizes the system that requires expertise and experience. A relative limitation of the neural network technique with its reliance on the qualities of the photovoltaic array that change with time, implying that the neural network must be periodically trained to ensure exact MPPs. The Inc-Cond strategy is the

one which supersedes over the previously mentioned downsides. In this strategy, the array terminal voltage is constantly balanced by the MPP voltage. It depends on the incremental and instantaneous conductance of the photovoltaic module.
It is clear that the MPP is located at the knee of the I-V curve, where the resistance is equal to the negative of differential resistance

$$\frac{dV}{dI} = -\frac{V}{I} \tag{6}$$

This is following the general rule used in the P&O method, in which the slope of the PV curve at the MPP is equal to zero

$$\frac{dP}{dI} = 0 \tag{7}$$

Equation (7) can be rewritten as follows:

$$\frac{dP}{dV} = I.\frac{dV}{dV} + V.\frac{dI}{dV} \tag{8}$$

$$\frac{dP}{dV} = I + V.\frac{dI}{dV} \tag{9}$$

and hence

$$I + V.\frac{dI}{dV} = 0 \tag{10}$$

which is the basic idea of the IncCond algorithm. One imperative point to specify is that (6) or (7) infrequently happens in practical usage, and a little error is typically allowed [14]. The size of this permissible error (e) decides the sensitivity of the system. This error is chosen concerning the swap between steady-state fluctuation and risk of fluctuating at a comparative working point.

From nonlinear characteristics of solar PV panel,

$$\frac{dI}{dV} = -\frac{I}{V} atMPP \tag{11}$$

$$\frac{dI}{dV} > -\frac{I}{V} LeftofMPP \tag{12}$$

$$\frac{dI}{dV} < -\frac{I}{V} RightofMPP \tag{13}$$

where I and V are the photovoltaic array yield current and voltage, individually. The left-hand side of the conditions represents to the Inc-Cond of the photovoltaic module, and the right-hand side specifies to the instantaneous conductance. From equation above (11)-(13), clearly when the ratio of change in the output conductance is equivalent to the negative output conductance, the solar array will work at the MPP. As it were, by looking at the conductance at each

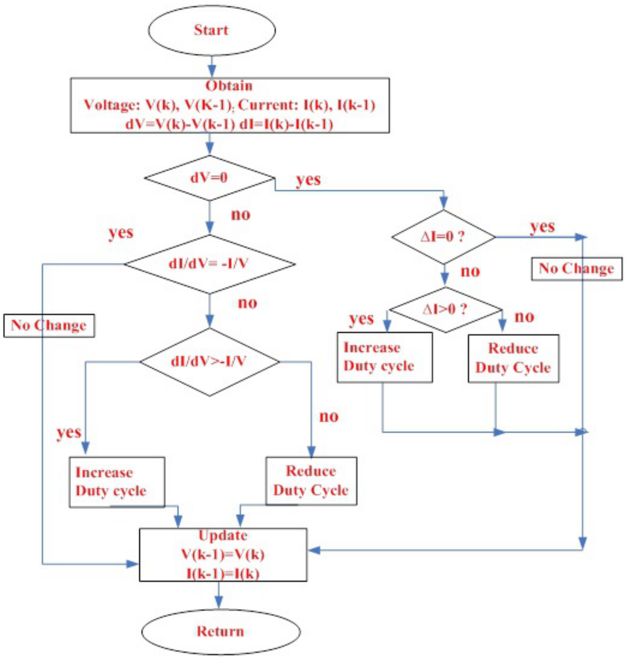


Fig. 7: *Inc-Cond MPPT controlling algorithm.*

testing time or sampling, the MPPT will track the greatest power of the PV module. The exactness of this strategy is demonstrated in [8], where it says that the Inc-Cond technique can track the genuine MPPs autonomous of PV array attributes. It is suggested to choose a small and positive digit [4], [1]. Thus, (10) can be rewritten as

$$I + V.\frac{dI}{dV} = error \tag{14}$$

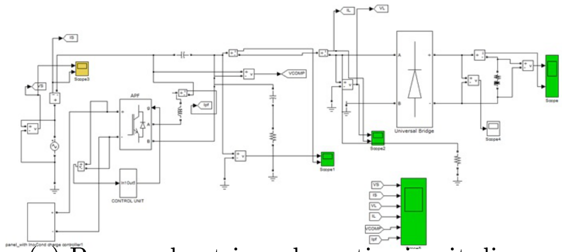
In this paper, the estimation of "error" was selected as 0.002 on the premise of the trial and error method. The flowchart of the Inc-Cond calculation within the direct control strategy is appeared in Fig.7. As indicated by the MPPT calculation, the duty cycle (D) is ascertained. This is the coveted duty cycle that the PV module must work on the subsequent stage. Setting another duty cycle in the system is rehashed by the examining time.

In order to implement the MPPT algorithm, a buck-boost dc/dc converter is used as depicted in Fig.8(b). The parameters L and C in the buck-boost converter must satisfy the following conditions [11]:

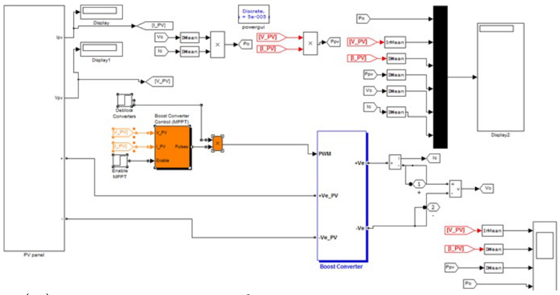
$$L > \frac{(1-D)^2 R}{2f} \tag{15}$$

$$C > \frac{D}{Rf\left(\frac{\Delta V}{V_{out}}\right)} \tag{16}$$

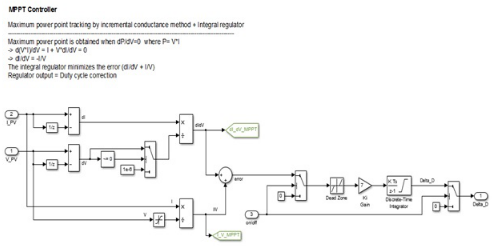
The buck-boost converter comprises of one switching device (MOSFET) that empowers it to turn on



(a) Proposed entire schematic circuit diagram



(b) Unmask view of PV panel with incremental conductance control approach



(c) Unmask view of Incremental Conductance (Inc-Cond)

Fig.8: *Proposed overall simulation setup of proposed THSeAF system.*

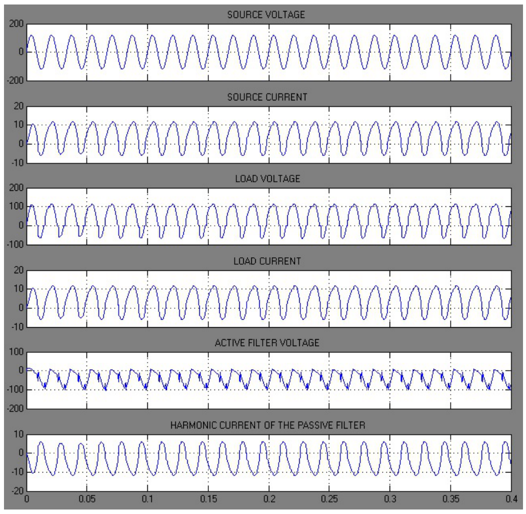


Fig.9: *waveforms of THSeAF in set up diagram a) voltage source b) current source c) load voltage d) load current e) active filter voltage compressor f) harmonic current passive filter.*

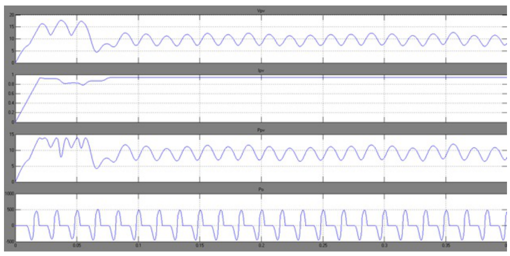


Fig.10: *waveforms of PV panel setup diagram a) Panel voltage (V_{pv}) b) Panel current (I_{pv}) c) Panel power (P_{pv}) d)output power (P_o).*

and off contingent upon the connected gate signal "D". The gate signal for the MOSFET can be gotten by contrasting the sawtooth waveform and the control voltage [7]. The difference in the reference voltage Δ Vref acquired by MPPT calculation turns into the contribution of the pulse width modulation (PWM). The PWM produces a gate signal to control the buck-boost converter and, in this way, most extreme power is tracked and conveyed to the AC side by means of a DC/AC inverter.

3. PROPOSED RESULTS AND DISCUSSIONS

The proposed transformer less HSeAF is simulated in MATLAB as shown in Fig.8. A single phase non-linear load with a rated power of 2KVA with 0.74 lag power factor is applied to Simulation [9]. A 2KVA, 123Vrms 60Hz variable source is used [10]. The THSeAF connected in series to the system to compensate the current harmonics and voltage distortions. A gain G=8 ohms equivalent 1.9P.U by referring is to control current harmonics. The capability to operate the system with low DC voltage is the main advantage of the proposed system[10]. DC auxiliary is given as 130Vdc. During voltage distortion the compensator controls the current harmonics, voltage magnitude at load and corrects power factor [11]. The simulated results of THSeAF are shown in Fig.9. which shows the improvement of source current [12].

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The grid is presently adjusted with shielding the system from current harmonics with a unity power factor operation [13]. Since the arrangement controlled source averts current harmonics, the source current is forced to be in phase with source voltage. The series compensator has the capability to regulate the load voltage so that the power factor becomes unity. The series compensator is used to control the power flow between two point of common coupling's PCC [8]. Fig.10 shows the variation of renewable solar photovoltaic panel voltage, current, and power.

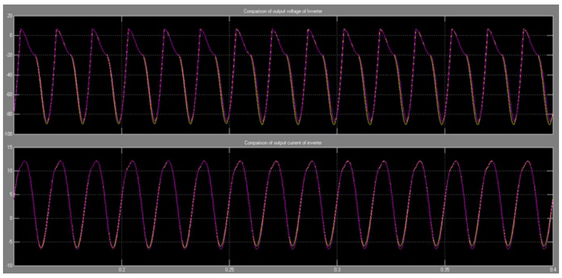

Fig.11: *comparison of Inc-Cond MPPT and P&O based MPPT fed PV system a) Output voltage of inverter b) Output current of inverter(Yellow colour represent-PV fed inverter output waveform, Pink represent-constant DC source fed inverter output waveform).*

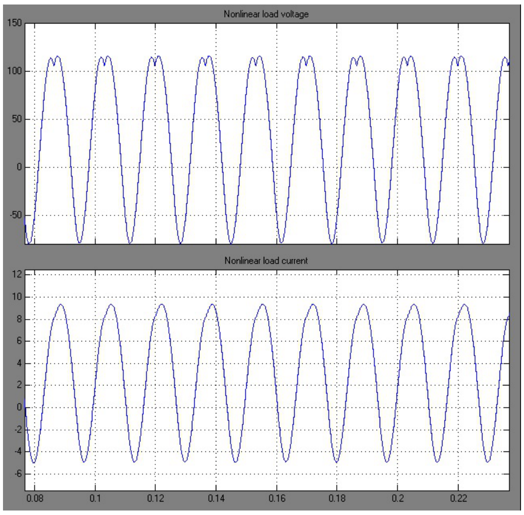

Fig.12: *Output nonlinear load voltage and current waveforms.*

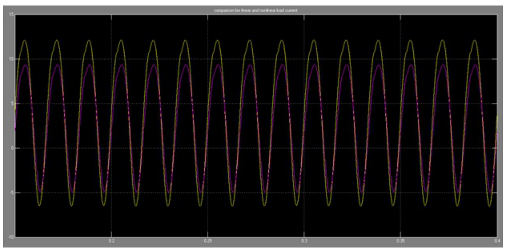

Fig.13: *Difference between linear and non-linear load current waveforms (Yellow colour represent-linear, Pink colour represent-nonlinear).*

Fig.11 displays the comparison of renewable photovoltaic fed H-bridge inverter and constant DC source input to the inverter. The PV fed inverter shows less oscillation compare to the constant DC source system. Fig.12 demonstrates the nonlinear load voltage and current waveforms. Followed by comparison of linear and non-linear load current waveforms displayed in Fig.13. from the figure clear out the proposed techniques reduced the harmonics level was totally eliminated.

4. CONCLUSION

The reason for this proposed framework is to enhance the power quality of the framework by compensating harmonic current and to enhance and manage the PCC voltage. By interfacing the auxiliary source it can check the power flow in the framework or system for renewable solar photovoltaic power supply, when critical loads are associated. The design was reproduced and approved. This dynamic compensator gives consistent and distortion free supply to the load terminals and furthermore it disposes of the source harmonic current and enhances power quality control nature of the network by secluding the transformer.

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