# Power Quality Improvement using UPFC with SOLAR CELLS by MPPT

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***Abstract*— The SOLAR CELLS play an important role in electric power generation with growing environmental concerns. The inter connection of solar cells sources are incorporated using power electronics converters, with the aim of improving power quality at the point of common coupling (PCC). This paper presents a novel idea where a UPFC is used innovatively as i) a load reactive power compensator ii) an interface unit between the grid and Solar cell energy source, and iii) as an effective method for real power exchange between the dynamic load system, grid and Solar cells energy source iv) Its providing fast –acting reactive power compensation on high-voltage electricity transmission networks. A controller unit is proposed for the UPFC based on modified Icosφ algorithm by which reactive power compensation and power factor correction is done and also real power support is provided by renewable energy source through UPFC. The performance of the proposed algorithm is compared with the modified Instantaneous Reactive Power Theory (IRPT) control algorithm to achieve the above objectives.**

*Keywords—solar cells source interfacing unit; Power Quality Improvement; reactive power compensation; power factor correction; Point of Common Coupling (PCC).*

## I. INTRODUCTION

With the continuous need for safe, reliable and quality electricity supply, more versatile methods of power generation are being implemented world-wide. Two technically challenging concepts to achieve the above stated goal are stated here. Firstly, Solar cell sources are made use of, due to the rising problems with the conventional fossil fuels and environmental factors. Secondly, a custom power device such as UPFC is used as an interfacing unit between grid, load and Solar energy source. The Solar cell source and UPFC unit are driven by a simple algorithm called modified Icosφ algorithm, which provides the necessary reactive power compensation, power factor correction and also control of real power flow from the source (grid) and Solar energy.

The theme of the paper is to improve the power quality of supply in locations where electric grids are weak or sensitive loads need to be protected against problems such as low power factor, voltage regulation, and reactive power compensation.

This paper also compares the performance of proposed modified Icosφ algorithm with the modified IRPT algorithm for UPFC control.

## II. PROPOSED CONFIGURATION FOR SOLLAR CELL SYSTEM INTERFACE

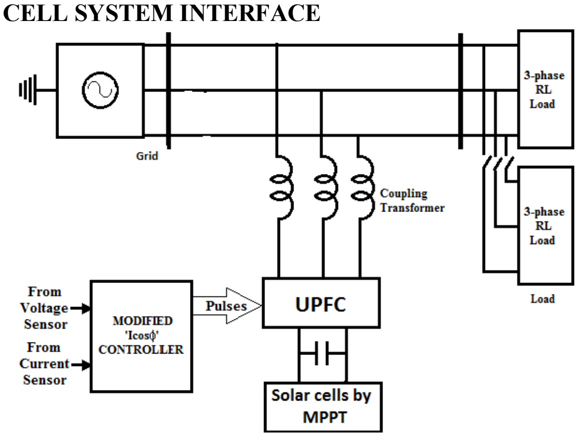


Figure.1 Schematic of the three phase grid system with the UPFC Interface for renewable energy source

The UPFC is a power electronics device based on the principle of injection or absorption of reactive current at the point of common coupling (PCC) to the power network. The main advantage of the UPFC is that the compensating current does not depend on the voltage level of the PCC and thus the compensating current is not lowered as the voltage drops. The other reasons for preferring a UPFC instead of an SVC are overall superior functional characteristics, faster performance ,smaller size ,cost reduction and the ability to provide both active and reactive power ,thereby providing flexible voltage control for power quality improvement. When a Solar cell energy source is used with power electronic interface, the need for the usage of additional converters and power conditioning equipments arises. The drawbacks of using these additional circuits are high switching loss, increased costs and a bulkier system; hence the proposed scheme replaces the need for additional converters with a UPFC unit.

The UPFC unit is intended for reactive power compensation as demanded by the load; the UPFC unit is an inverter with DC link capacitor which gets its control pulses from a controller circuit.



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The control pulses are generated using modified Icosφ algorithm, which in turn causes the UPFC to provide the real power support from the Solar cell energy source and reactive power compensation as and when required by the load. The proposed configuration of the three phase grid system with UPFC interface for Solar cell energy source is shown in Fig.1.This system configuration comprises of a three phase source (grid) of 400V, 50Hz, and two linear RL loads of rating 5.6kW and 3kVAr are switched at different time intervals.

**III MAXIMUM POWER POINT TRACKING (MPPT)**

Maximum power point tracking (MPPT) enables to increase efficiency of electricity production of photovoltaic (PV) module .To reach the maximum instantaneous power the controller must adjust the load of PV module according MPPT algorithm depending on varying cloudiness and temperature of the module. The controller must quickly respond to the mentioned and similar factors, and to assess their impact on the solar module, and adjust battery charging modes. The power generated by PV module depends on speed and accuracy of load matching.

Tracking of maximum power point (MPP) is provided by electronic system used to exploit maximum power from PV modules, which these modules are capable to produce. Controller with MPPT algorithm follows the maximum voltage and current intersection point of the module and guarantees the highest received power.

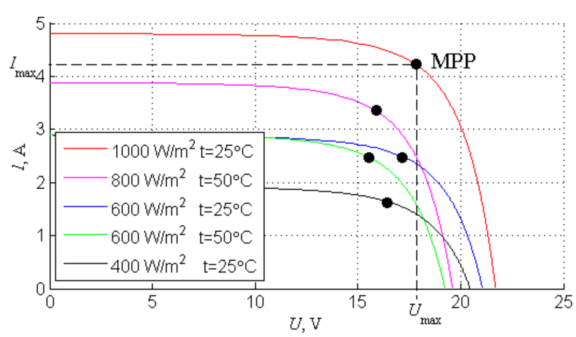


Figure. 2. MPP at different SEF and temperatures.

**IV. PROPOSED CONTROL ALGORITHMS**

***A. Concept Modified Icosφ control algorithm***

The Icosφ algorithm is able to provide harmonic, reactive and unbalance compensation in a three phase system with Balanced/unbalanced source and load conditions. This has been proved and reported in [1]. Here the algorithm is aimed to provide reactive power compensation, power factor correction and real power exchange from the renewable energy source.

The sensed load current and source voltage are given as the input to the controller circuit. The load current is given as an input to a second-order low pass filter (which has 50 Hz as its cut-off frequency),so as to extract the fundamental load current which has an inherent phase shift of 90°.„Detect negative‟ logic is being used to detect the zero crossing instant of the source phase voltage. The corresponding response is given as one of the input to the sample and hold circuit and the other input is derived from the second order low pass filter along with the 90° phase shift. The output of the sample and hold circuit is the required amount of Icosφ magnitude. The Icosφ magnitude is now multiplied with the unit amplitude of the corresponding source phase voltage to get the desired mains current for each phase.

The reference compensation currents for the UPFC are deduced as the difference between the actual load Current and the desired mains current in each phase. The detailed mathematical analysis about the „modified Icosφ‟ algorithm is explained below:

Let $U_a$, $U_b$, $U_C$ be the unit amplitude templates of the phase to-ground source voltages in the three phases, respectively

$U_a = 1.\sin \omega t;$

$U_b = 1.\sin(\omega t - 120°);$

$$U_c = 1.\sin(\omega t + 120); \qquad (1)$$

The desired (reference) source currents in the three phases are therefore given as:

$I_{sa(ref)} = K\,|I_{s(ref)}| \times Ua = K\,|I_{s(ref)}|\,\sin \omega t$

$I_{sb(ref)} = K\,|I_{s(ref)}| \times Ub = K\,|I_{s(ref)}|\,\sin(\omega t - 120)$

$$I_{sc(ref)} = K\,|I_{s(ref)}| \times Uc = K\,|I_{s(ref)}|\,\sin(\omega t + 120) \qquad (2)$$

Where K is the load factor which determines how much real power has to be supplied by the source/grid. The reference compensation currents for the UPFC is thereby deduced as the difference between the actual load current and the desired source current in each phase

$I_{a\,(comp)} = I_{La} - I_{sa(ref)}$; $I_{b(comp)} = I_{Lb} - I_{sb(ref)}$;

$$I_{LC\,(comp)} = I_{LC} - I_{SC(ref)}; \qquad (3)$$

Further, a hysteresis current controller is used such that, the relay is on till compensation current drops below the value of switch off point. The relay is off till compensation current exceeds the value of switch on point. Now this pulse is sent through a data type conversion block and a NOT gate in order to get the complimentary pulse for the UPFC unit.

The control over the real power exchange has been introduced by including gain factor „k‟. The magnitude of the gain is chosen by the user depending upon the load Requirements and availability of renewable energy source Power generation. For instance, when the magnitude of the gain is chosen as ½, the real power supply from the mains is reduced by half and the rest is supplied by Solar cell energy source using the UPFC circuit as an interface.



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### B. Concept of Modified IRPT control Algorithm

In this algorithm proposed by Akagi [5], the instantaneous imaginary power, which is a new electrical quantity, is introduced in three phase circuits. The three phase mains voltages and load currents of the system are sensed and converted into the α-β (two) phase plane using Park's transformation.

$$\begin{bmatrix} e_\alpha \\ e_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (4)$$

where $e_a, e_b, e_c$ are the three phase mains voltages.

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (5)$$

Where $i_{La}$ , $i_{Lb}$ ,$i_{Lc}$ are the three-phase load currents.

The instantaneous real power *Lp* and the instantaneous imaginary power *Lq* consumed by load current are derived as,

$$p_L = e_\alpha i_{L\alpha} + e_\beta i_{L\beta}$$

$$q_L = e_\alpha i_{L\beta} - e_\beta i_{L\alpha} \quad (6)$$

$p_L$ and $q_L$ are made up of a DC and an AC component, so that they may be expressed by

$$p_L = \tilde{p}_L + \bar{p}_L$$

$$q_L = \tilde{q}_L + \bar{q}_L \quad (7)$$

The reference filter currents are determined using the Expression given below,

$$p_f^* = \tilde{p}_L + (1-k)\,\bar{p}_L$$

$$q_f^* = \tilde{q}_L + \bar{q}_L \quad (8)$$

Where "k" is the load factor which determines the amount of real power supplied by the source .This is the modification in IRPT proposed by the authors to bring the control of real power from the renewable energy source.

For the purpose of current harmonic suppression and of reactive power compensation, the AC term of *Lp*, fraction of DC term of *L p* and all the terms of *Lq* must be compensated by the active power filter. Hence, the reference signal of the compensation current in the d- q axes can be represented as

$$\begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} = \begin{bmatrix} e_\alpha & e_\beta \\ -e_\beta & e_\alpha \end{bmatrix}^{-1} \begin{bmatrix} p_f^* \\ q_f^* \end{bmatrix} \quad (9)$$

Applying inverse Park's transformation on the above Signals give the reference compensation currents in the three phases as,

$$\begin{bmatrix} i_{ca} \\ i_{cb} \\ i_{cc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 0 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} \quad (10)$$

### V. SIMULATION OF UPFC BASED INTERFACE FOR SOLAR CELL ENERGY SOURCE

The simulation of the three phase grid system supplying linear RL-load and UPFC interface for renewable energy source has been done using MATLAB Simulink. For the simulation purpose the renewable energy source output is considered as a rectified DC voltage source connected to DC link of UPFC to provide the real power support for the load. The following section is divided into two sub-sections for good understanding of stated objective of the system.

#### *A . Three Phase grid system supplying RL Load*

The power system consists of a three phase source of 400V, 50Hz which supplies real and reactive power to a combination of two numbers of RL linear loads switched at different time interval behaves as a dynamic load for the system. In this condition, source (grid) is responsible for handling the total real power and reactive power demands of the load.

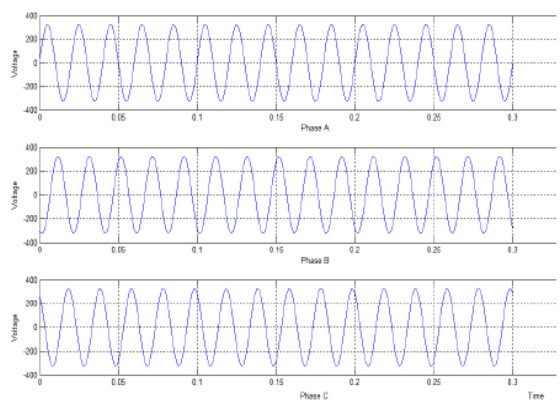

Figure.3.Three phase voltages source (grid) side

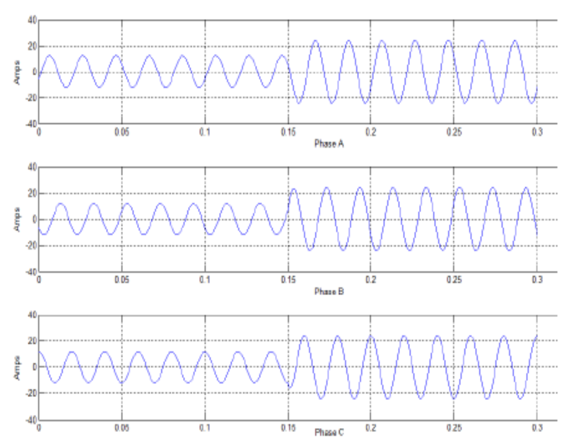

Figure.4.Three phase currents of source (grid) side



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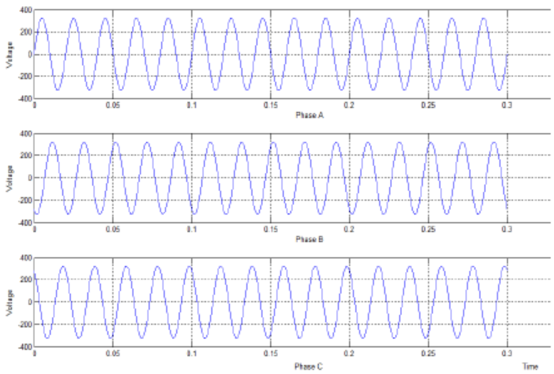


Figure.5. Three phase load voltages of RL linear Load

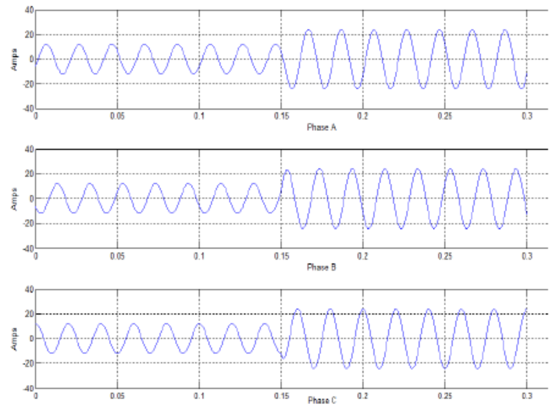


Figure.6.Three phase load currents of RL linear Load

Figure.3, Figure.4 are the voltage and current wave forms of the three phase system, taken at the source(grid)side and Figure.5, Figure.6 are voltage and current wave forms measured at load side of the system. From Figure.5 one can easily understand the second load is switched on after the time t= 0.15sec and current magnitude changed to higher level. This current is lagging the source voltage by some angle based on reactive power requirement of linear dynamic loads.

### B. *UPFC as an Interfacing unit for real power sharing between grid and SOLAR CELL energy source*

The UPFC acts as an effective interfacing link between the renewable energy source and grid system. The UPFC unit performs regular role of delivering the required amount of reactive power and power factor correction, which works with the gating pulses generated from the modified Icosφ based controller circuit.

In addition to merely being an interfacing unit, another imperative function of a UPFC is the ability of real power exchange from solar energy source to load and grid. It has been perceived that when the load requires power that is more than the power supplied by the source, the UPFC unit takes an active part and supplies the required active and reactive power. Similarly, when the renewable energy output is higher than that of the load power, the UPFC unit delivers the excessive power back to the grid. But a small amount of power loss will take place at UPFC unit at light load conditions. Recent advances in the power system handling capabilities of static switches have made the use of the voltage source inverter (VSI) feasible at both transmission and distribution levels. This paper is focused on power quality improvement in grid by using maximum power point tracking in solar energy cells.

The control strategies were tested using a power system distribution model. The Series converter can eliminate the voltage flickers that exist in the same branch the series converter is located in, while the shunt converter can eliminate the current harmonics. The UPFC can remove both the current harmonics & voltage flicker from the system. These cases have been proven in the simulation analysis and the results are tabulated in Table I.

**TABLE I. POWER SHARING BETWEEN GRID AND SOLAR ENERGY SOURCE USING UPFC INTERFACE**

| Time | Power Sharing | | |
|---|---|---|---|
| | Power duration by load | Power supplied by Solar cell energy sources via UPFC | Power supplied by source/Grid |
| Load 1 Time<0.15s | P=5.19KW Q=2.76KVar | P=5.19KW Q=2.76KVar | P=5.19KW Q=2.76KVar |
| Load1+Load2 Time>0.15s | P=5.19KW Q=2.76KVar | P=5.19KW Q=2.76KVar | P=5.19KW Q=2.76KVar |

From the Table I and Figure.9, it is clear that for a simulation period of less than 0.15sec, only one load demanding a real power of 5.19KW and reactive power of 2.76KVar. After 0.15sec the second load gets switched on, consuming a total real and reactive power of 10.4KW and 5.52KVar.This demand is met by the source by delivering real power of 2.595KW and reactive power of -0.123KVar as shown in Figure.7. From Figure.8 and Table I, for the same period of time i.e for period less than 0.15sec, the solar energy source supports a real power of 2.395KW and a reactive power of 2.883KVar, including loss. For the time period greater than 0.15sec the Solar energy source provides a real power of 5.250KW and reactive power of 5.761KVar through UPFC interface at the PCC.

In this period the source (grid) is supplying only the real power of 2.595KW and 5.2KW. The simulation results of the two linear RL loads switched on at different instants are given below. Figure.7 shows the active and the reactive power delivered by the source and Figure.8 shows the active and reactive power support from the renewable energy source through the UPFC interface at the PCC. The total real and reactive power required by the load is shown in Figure.8. This total demand is supplied by the source and Solar energy through UPFC interface.

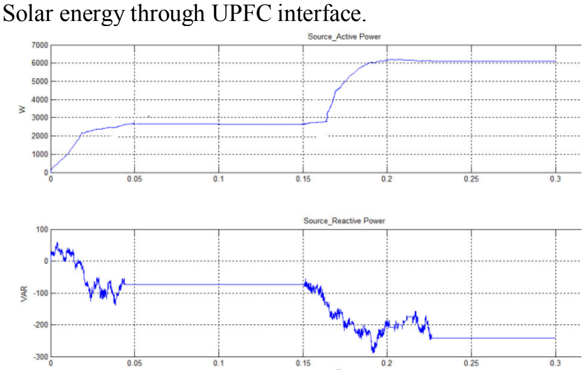


Figure .7.Active power and Reactive power at source



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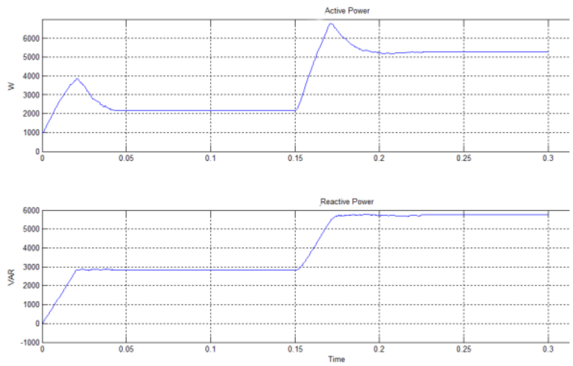


Figure.8. Active and Reactive power of UPFC unit at PCC

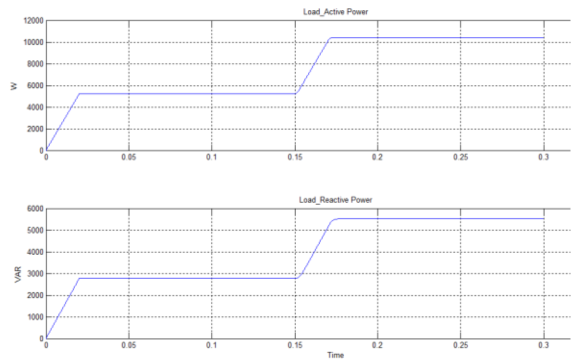


Figure.9. Active and Reactive power of dynamic linear loads.

## V. POWER FACTOR CORRECTION WITH SOLAR ENERGY SOURCE SUPPORT BY UPFC INTERFACE

The following simulation results are shown for the Modified Icosφ controller performance with dynamic load system. Figure.10. shows that the three phase current waveform of dynamic load.

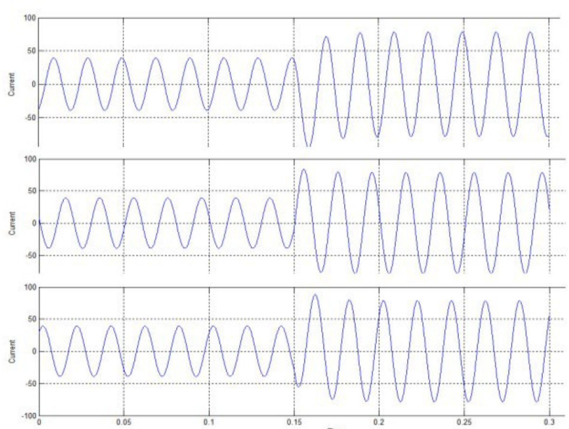


Figure.10. Three phase load currents for a dynamic load system

Figure.11. shows the source voltage and load current along with the comparison of reference current generated by the Modified Icosφ controller and the actual current produced by the UPFC for reactive power compensation and power factor correction.

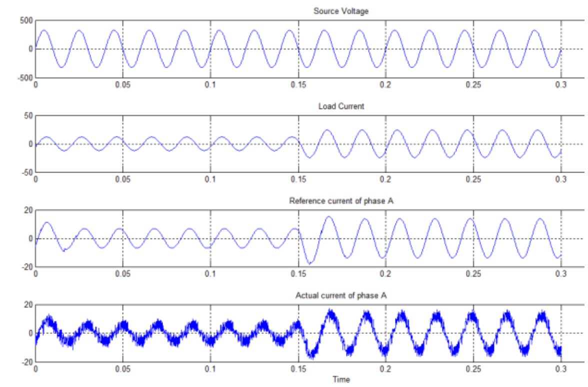


Figure.11. Source voltage, load current, actual current and reference current

Figure.12. shows the load current, phase shifted load current, sample and hold output that represents the Icosφ magnitude, desired source current which has to be supplied by the source (grid) and the UPFC reference current generated by the Modified Icosφ controller for the dynamic loads which has been switched on at different timings i.e for periods of less than 0.15 sec and greater than 0.15 sec. This shows the adoptability of modified Icosφ controller for dynamic varying nature.

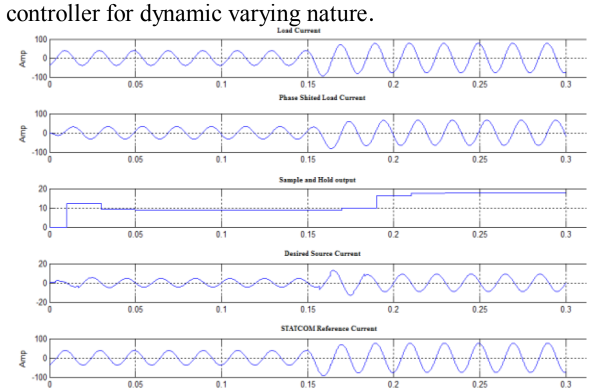


Fig.12. Modified Icosφ controller performance comprising of load current, phase shifted load current, sample and holed output, desired source

Figure.13. shows the load current, source voltage, along with the reference current generated by the Modified IRPT controller and actual current after compensation for the dynamic loads which has been switched on at above mentioned time periods of less than 0.15sec and greater than 0.15 sec.

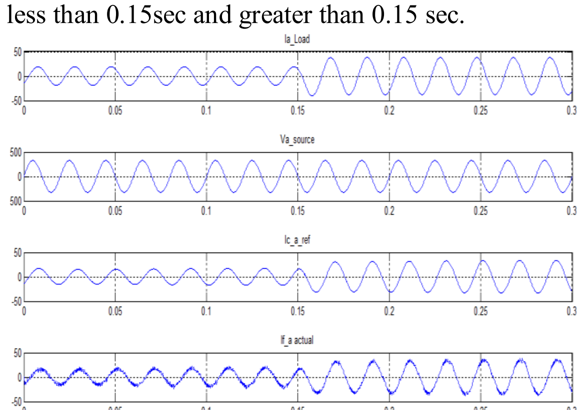


Figure.13. Modified IRPT controller output comprising of load current, source voltage, reference and actual currents



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Figure.14. shows the phase 'a' grid voltage and current after compensation. This waveform makes clear that grid voltage and current are in phase and thereby the power factor is virtually equal to unity hence it is proven that the power factor of the three phase system is improved using the modified Icosφ controller.

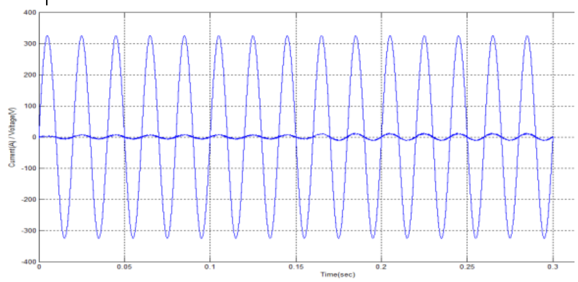

Figure.14 Source voltage and current of phase-a for p.f verification using modified Icosφ controller.

Figure.15 shows the phase „a‟ grid voltage and current after the compensation. Power factor is improved using modified IRPT algorithm, but when compared to the performance of the modified Icosφ control algorithm the current supplied by the grid is significantly increased to a large extent, hence validating the superiority of the modified Icosφ control algorithm for power factor correction.

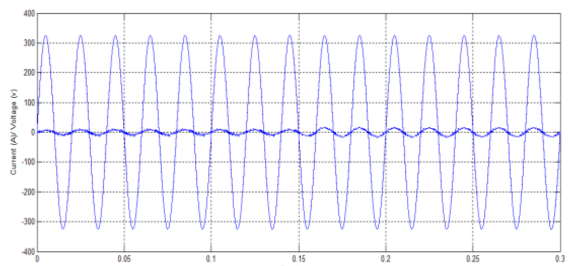

Figure.15.Source voltage and current of phase –a for p.f verification using modified IRPT controller.

## VI. CONCLUSION

The modified Icosφ control algorithm and modified instantaneous reactive power theory (IRPT) has been developed and simulated with UPFC interface for renewable energy source. The results shown above prove that power factor correction, reactive power compensation achieved by the instigation of the modified Icosφ algorithm and modified IRPT control algorithm.

It has also been proven that the modified „Icosφ‟ algorithm is a feasible solution for a dynamic load system such that it works effectively for power sharing issues. Also, a comparison between the modified Icosφ algorithm and the modified IRPT control algorithm has been done to validate the power sharing and power factor correction. Finally UPFC is found to be an effective interface unit between the solar energy source and the grid, acting as an important link for effective power compensation.

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