# Power Quality Improvement using STATCOM with Renewable Energy Sources

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***Abstract*—The renewable energy sources play an important role in electric power generation with growing environmental concerns. The inter connection of renewable energy 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 STATCOM is used innovatively as i) a load reactive power compensator ii) an interface unit between the grid and renewable energy source, and iii) as an effective method for real power exchange between the dynamic load system, grid and renewable energy source. A controller unit is proposed for the STATCOM 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 STATCOM. The performance of the proposed algorithm is compared with the modified Instantaneous Reactive Power Theory (IRPT) control algorithm to achieve the above objectives.**

***Keywords--Renewable energy 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, renewable energy 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 STATCOM is used as an interfacing unit between grid, load and renewable energy source. The renewable energy source and STATCOM 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 renewable 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 STATCOM control.

## II. PROPOSED CONFIGURATION FOR RENEWABLE ENERGY SYSTEM INTERFACE

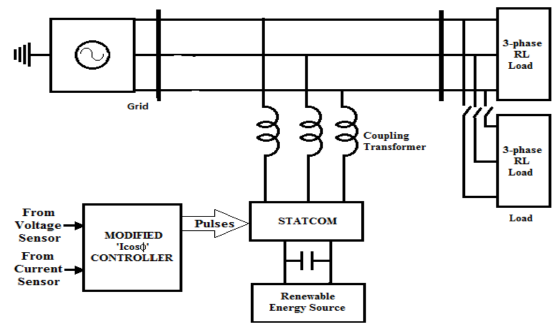


Fig.1 Schematic of the three phase grid system with the STATCOM Interface for renewable energy source

The STATCOM 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 STATCOM 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 STATCOM 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 renewable 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 STATCOM unit.

The STATCOM unit is intended for reactive power compensation as demanded by the load; the STATCOM unit is an inverter with DC link capacitor which gets its control pulses from a controller circuit. The control pulses are generated using modified Icosφ algorithm, which in turn causes the STATCOM to provide the real power support from the renewable energy source and reactive power compensation as and when required by the load. The proposed configuration of the three phase grid system with STATCOM interface for renewable energy source is shown in Fig.1.This system configuration comprises of a

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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. PROPOSED 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 STATCOM 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 ua, ub, uc be the unit amplitude templates of the phase-to-ground source voltages in the three phases, respectively

$$U_a = 1.\sin \omega t; U_b = 1.\sin(\omega t - 120°); U_c = 1.\sin(\omega t + 120°); \quad (1)$$

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

$$I_{sa(\mathrm{ref})} = K\left|I_{s(\mathrm{ref})}\right| \times U_a = K\left|I_{s(\mathrm{ref})}\right| \sin\omega t$$

$$I_{sb(ref)} = K\left|I_{s(ref)}\right| \times U_b = K\left|I_{s(ref)}\right| \sin(\omega t - 120°)$$

$$I_{sc(ref)} = K\left|I_{s(ref)}\right| \times U_c = K\left|I_{s(ref)}\right| \sin(\omega t + 120°) \quad (2)$$

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 STATCOM is thereby deduced as the difference between the actual load current and the desired source current in each phase

$$I_{a(comp)} = I_{La} - I_{sa(ref)}; I_{b(comp)} = I_{Lb} - I_{sb(ref)};$$
$$I_{Lc(comp)} = I_{Lc} - I_{sc(ref)}; \quad (3)$$

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 STATCOM 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 renewable energy source using the STATCOM circuit as an interface.

### *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 $p_L$ and the instantaneous imaginary power $q_L$ 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,

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

$$q_f^{\,*} = \tilde{q}_L + \bar{q}_L \tag{8}$$

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 $p_L$ , fraction of DC term of $p_L$ and all the terms of $q_L$ 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

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

Applying inverse Park’s transformation on the above signals gives the reference compensation currents in the three-phases as,

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

## IV. SIMULATION OF STATCOM BASED INTERFACE FOR RENEWABLE ENERGY SOURCE

The simulation of the three phase grid system supplying linear RL-load and STATCOM 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 STATCOM 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.

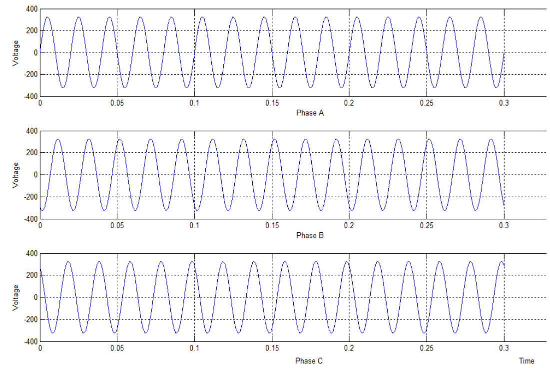

Fig.2.Three phase voltages source (grid) side

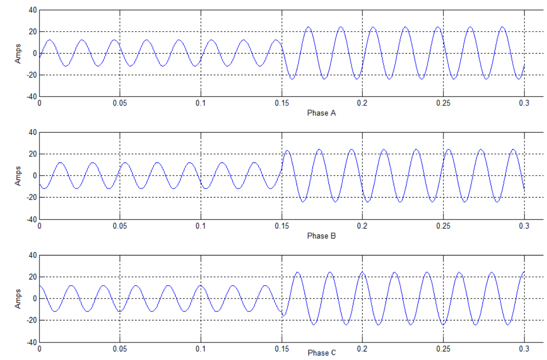

Fig.3.Three phase currents of source (grid) side

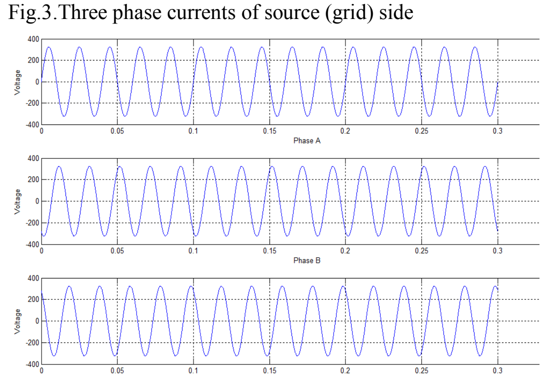

Fig.4. Three phase load voltages of RL linear Load

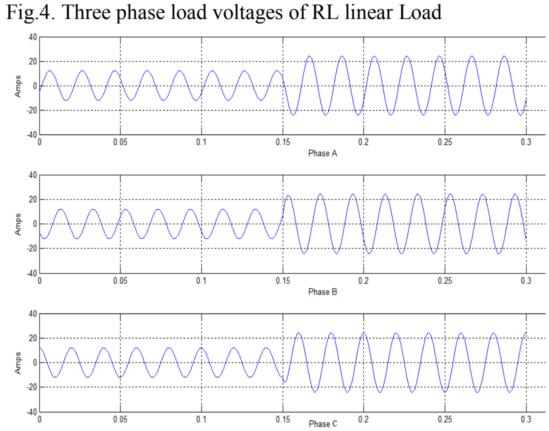

Fig.5.Three phase load currents of RL linear Load

Fig.2, Fig.3 are the voltage and current wave forms of the three phase system, taken at the source(grid)side and Fig.4, Fig.5 are voltage and current wave forms measured at load side of the system. From Fig.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.STATCOM as an Interfacing unit for real power sharing between grid and Renewable energy source*

The STATCOM acts as an effective interfacing link between the renewable energy source and grid system. The STATCOM 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 STATCOM is the ability of real power exchange from renewable 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 STATCOM 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 STATCOM unit delivers the excessive power back to the grid. But a small amount of power loss will take place at STATCOM unit at light load conditions .These cases have been proven in the simulation analysis and the results are tabulated in Table I.

TABLE I. POWER SHARING BETWEEN GRID AND RENEWABLE ENERGY SOURCE USING STATCOM INTERFACE

| **Time** | **Power Sharing** | | |
|---|---|---|---|
| | ***Power drawn by Load*** | ***Power Supplied by Renewable Energy Source via STACOM*** | ***Power Supplied by Source/grid*** |
| Load 1 time < 0.15s | P=5.19 kW Q=2.76 kVar | P= 2.395kW Q= 2.883kVar | P=2.595kW Q=-0.123kVar |
| Load1+ Load 2 time > 0.15s | P=10.4kW Q=5.52 | P=5.250kW Q=5.761kVar | P=5.2kW Q=-0.242kVar |

From the Table I and Fig.8, 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 Fig.6. From Fig.7 and Table I, for the same period of time i.e for period less than 0.15sec, the renewable 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 renewable energy source provides a real power of 5.250kW and reactive power of 5.761kVar through STATCOM 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. Fig.6 shows the active and the reactive power delivered by the source and Fig.7 shows the active and reactive power support from the renewable energy source through the STATCOM interface at the PCC. The total real and reactive power required by the load is shown in Fig.8. This total demand is supplied by the source and renewable energy through STATCOM interface.

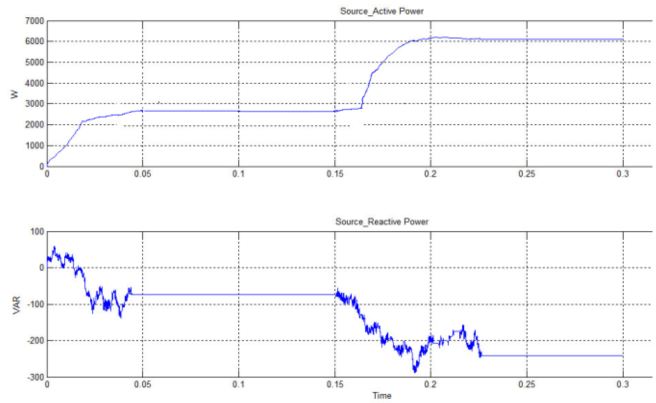

Fig .6.Active power and Reactive power at source

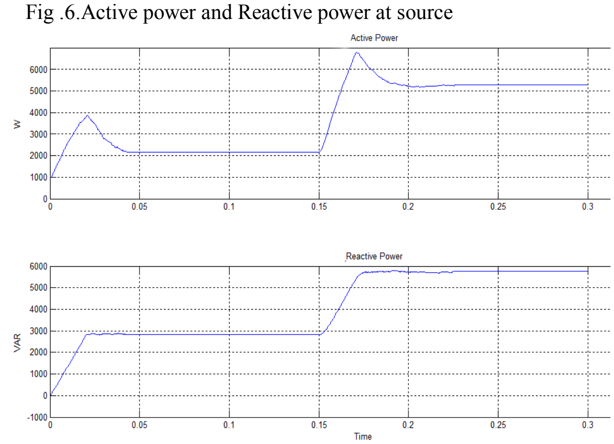

Fig.7. Active and Reactive power of STATCOM unit at PCC

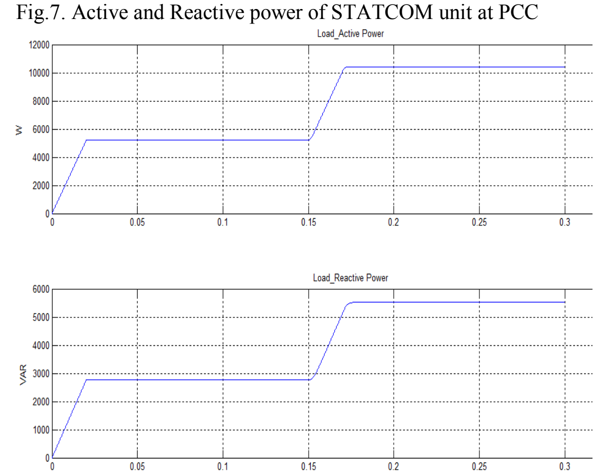

Fig.8. Active and Reactive power of dynamic linear loads.

## V. POWER FACTOR CORRECTION WITH RENEWABLE ENERGY SOURCE SUPPORT BY STATCOM INTERFACE

The following simulation results are shown for the Modified Icosφ controller performance with dynamic load system. Fig.9. shows that the three phase current waveform of dynamic load.

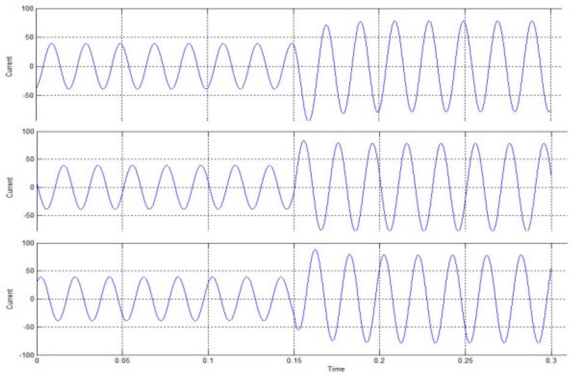


Fig.9. Three phase load currents for a dynamic load system

Fig.10. 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 STATCOM for reactive power compensation and power factor correction.

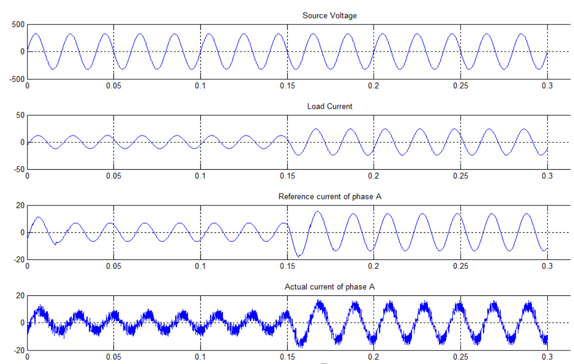


Fig.10. Source voltage, load current, actual current and reference current

Fig.11. 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 STATCOM 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.

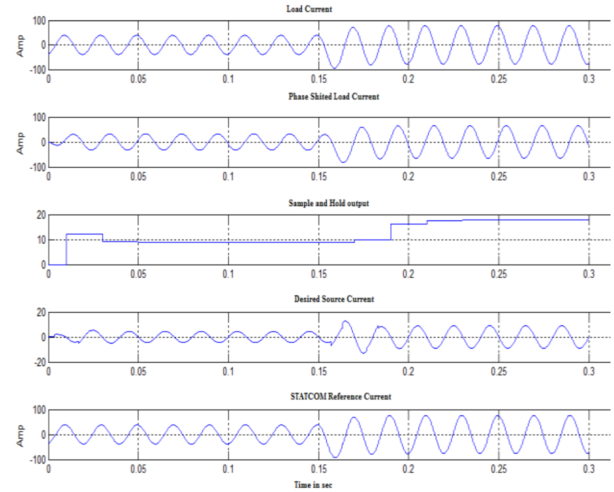


Fig.11. Modified Icosφ controller performance comprising of load current, phase shifted load current, sample and holed output, desired source

Fig.12. 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.

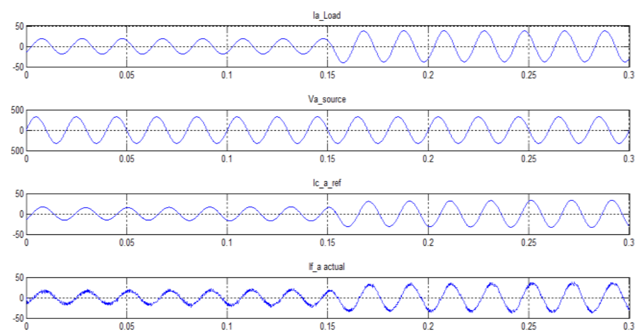


Fig.12. Modified IRPT controller output comprising of load current, source voltage, reference and actual currents

Fig.13. 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.

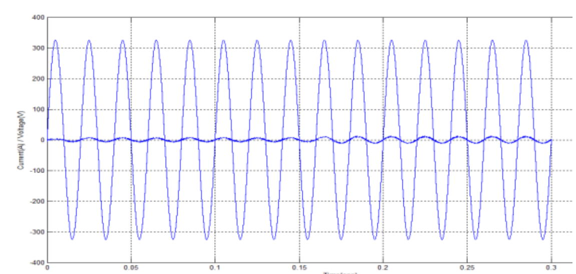

Fig.13 Source voltage and current of phase-a for p.f verification using modified Icosφ controller.

Fig.14 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.

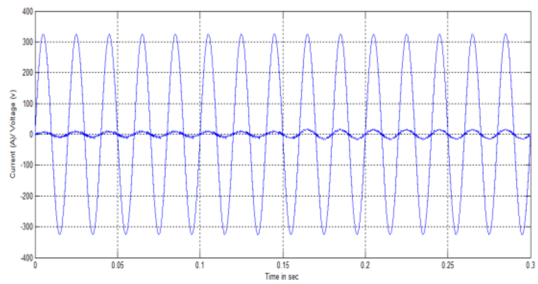

Fig.14.Source voltage and current of phase –a for p.f verification using modified IRPT controller.

## VI. Conclusion

The modified Icosφ control algorithm and modified instantaneous reactive power theory (IRPT) has been developed and simulated with STATCOM 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, STATCOM is found to be an effective interface unit between the renewable energy source (RES) and the grid, acting as an important link for effective power compensation.

## Acknowledgment

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