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"Enhancing Power Quality Through the Integration of 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 project presents the enhancement of voltage sags/swell; harmonic distortion and low power factor using Static Compensator (STATCOM). The simulations were performed using MATLAB SIMULINK.

***Key Words*:** Renewable energy, Static Compensator, Power generation, simulations.

1.INTRODUCTION

Now a days due to increased power quality difficulties by using of switch off/on induction loads, nonlinear load and acceptance engine and so on in local and enterprises, control quality (PQ) issues, for example, music, flash, and awkwardness have created genuine concerns. What's more, sudden strikes on transmission lines, exchanging of capacitor banks, and numerous system Faults can likewise bring about PQ issues, for example, homeless people, voltage list/swell, and intrusion. Then again, an ascent of delicate burdens including computerized hardware and complex process controllers needs an unadulterated sinusoidal supply voltage for the best possible load operation. To meet power quality to as far as possible need specific kind of remuneration. In a couple of years back to alleviate the power quality inconveniences in the dispersion framework by utilizing detached channels like capacitor banks. Now this research successful very fast to mitigate the power quality problems with help of power conditioning devices. The power conditioning devices are dynamic voltage.

Aim of this research with the uninterrupted need for safe, reliable and quality electricity supply, more versatile methods of power generation are being employed 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 difficulties with the conventional fossil fuels and environmental factors. Furthermore, a custom power gadget, for example, STATCOM is utilized as an interfacing unit between network, stack and renewable vitality source. The renewable vitality source and STATCOM unit are driven by a basic calculation called IRPT calculation, which gives the crucial responsive power pay, control consider remedy furthermore controller of genuine power spill out of the source (lattice) and renewable vitality. the power quality of supply in areas where electric frameworks are feeble or delicate burdens fundamental to be ensured against issues, for example, low power consider, voltage control, and responsive power pay.

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This paper discusses the increase power factor and reduces the harmonics distortion of system. Poor power factor costs our community in improved electricity charges and unnecessary effect in the system and poor power quality. In electrical plants the load draw from the system electric power (dynamic) as power supply source (e.g. PCs, printers, and so forth.) or change over it into another type of vitality (e.g. electrical lights or stoves) or into mechanical yield (e.g. electrical engines) or rectifier. To smooth such negative impact, the powers consider adjustment of the electrical plants is completed. The power calculate redress got by utilizing power figure rectification changes banks to create locally the receptive vitality fundamental for the exchange of electrical valuable power, permits a superior and more discerning specialized sparing administration of the plants. The framework is equipped for amending power considers up to solidarity or modifying it as indicated by client seek. The proposed single-phase and three-phase automatic power factor correction systems have certain reactive current or reactive power ratings. When the detected reactive power absorbed by the load is more than the compensator rating, the power factor will not be corrected to unity, but certainly will be improved and the apparent power supplied by the ac supply will be reduced. These systems respond almost linearly throughout their pre-assigned areas of operation. They achieve better power quality by reducing the apparent power drawn from the ac supply and minimizing the power transmission losses. In addition, no harmonics disturbing the power system network are released, and hence no filtering is required. The proposed system performs better than the traditional methods in mitigating harmonics and power factor improvement. Power quality has genuine financial ramifications for clients,

utilities, and electrical hardware producers. Progress in power electronics innovation have permitted the improvement of different sorts of controlled hardware VAR compensator for power framework applications, however, power factor correction switches are the most solid ones. Since they show high adaptability in outline philosophy and display sensible reaction among quick changing situations. By interfacing power consider remedy switch it likewise enhances control quality. The load will be changed in nonlinearly then the reactive power compensation will be increased so the power system losses are increased. Due to This nonlinear load the current harmonics are increases in the transmission lines, rotating machines, and transformers. Furthermore, harmonics and unbalance load causes the oscillatory torque in the sensitive equipment it's leading to malfunctions of the equipment's, and also interference with communication circuit. So, to conquer these harmonics current by utilizing the Active Power Filter (APF) which have been effectively created Resent days the fossil fuel is the real part in the energy generation, yet its prompt a noteworthy ecological issue so to keep away from these issues the humankind to search for option assets in power generation. Enthusiasm for renewable energy is expanding because of worries about a dangerous atmospheric devation, air quality, and manageability. Renewable energy source (RES) incorporated at the dissemination level is named as distributed generation (DG) the current controlled voltage source inverters are utilized to interface the discontinuous RES in conveyed framework. To play out the dynamic power stream control there is no need of External equipment gadgets of the proposed technique. The Renewable producing units with the dynamic channel ability may assume a critical part in power quality administration in future power systems.

2. PROBLEM SPECIFICATIONS

To understand power factor, we'll first begin with the meaning of some essential terms:

KW is Working Power (additionally called Actual Power or Active Power or Real Power). The power really powers the equipment and performs valuable work. KVAR is Reactive Power. The power attractive gear (transformer, motor and relay) requirements to create the magnetizing flux. KVA is Apparent Power. It is the "vectorial summation" of KVAR and KW.

Power Factor (P.F.) is the ratio of Working Power to Apparent Power.

$$\text{P. F.} = \frac{\text{KW}}{\text{KVA}}$$

$$\text{P. F.} = \frac{\text{KW}}{\text{KW} + \text{KVR}}$$

Thus, for a given KVA:

The lower your ratio of KW to KVA thus, the lower your power factor. The higher your ratio of KW to KVA your power factor approaches 1.0. The distortion in the quality of supply power can be introduced/ enhanced at various stages; however; some of the primary sources of distortion can be identified as below:

A. Power Electronic Devices
B. IT and Office Equipment's
C. Arcing Devices
D. Load Switching
E. Large Motor Starting
F. Embedded Generation
G. Electromagnetic Radiations and Cables
H. Storm and Environment Related Causes etc.

Some of the common power quality issues and their prominent impact are Harmonics: Sinusoidal component of a periodic wave having a frequency that is an integral multiple of the fundamental frequency. If the fundamental frequency is 60 Hz, then the second harmonic is a sinusoidal wave of 120 Hz, the fifth harmonic is a sinusoidal wave of 300 Hz, and so on Excessive losses and heating in motors, capacitors and transformers joined to the system.

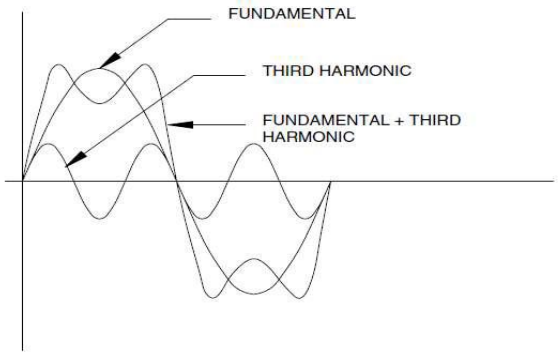

Fig -1: Fundamental, second, and third harmonic frequency waveform

Flicker: Variation of info voltage adequate in span to permit visual perception of an adjustment in electric light source power. Quantitatively, flash might be passed on as the adjustment in voltage over ostensible communicated as a percent. For instance, if the voltage at a 120-V circuit ascends to 125 V and after that drops to 117 V, the flash, f , is ascertained as f = 100 × (125 – 117)/120 = 6.66%.Visual aggravation, presentation of numerous symphonious modules in the supply control and their associated gear.

Transients: Sub cycle inconvenience in the AC waveform proves by a sharp, short brokenness of the waveform. This might be of either extremity and might be added substance or subtractive from the ostensible waveform. Homeless people happen when there is a sudden change in the voltage or the current in a power system. Transients are short-duration events, the features of which are predominantly determined by the resistance, inductance, and capacitance of the power system network at the point of interest. The primary characteristics that define a transient are the peak amplitude, the rise time, the fall time, and the frequency of oscillation. Figure 2 shows a transient voltage waveform at the output of a power transformer as the result of switching-in of a motor containing power factor correction capacitors Tripping, components failures, flashover of instrument insulation hardware booting, software glitches, poor product quality etc.

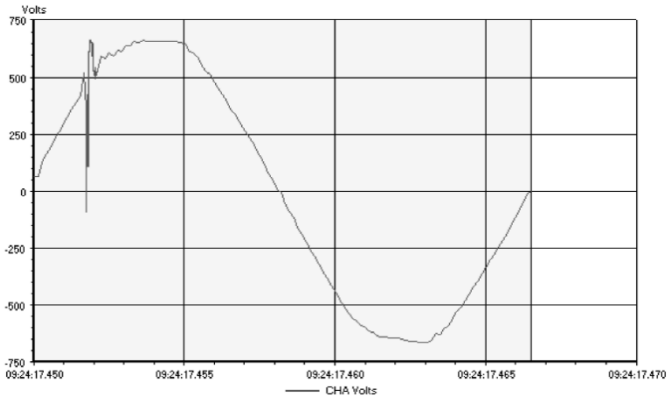

Fig-2: Transient due to motor starting

Voltage sags: RMS decrease in the AC voltage at power frequency from half of a cycle to a few moments' span. Figure 1.3 demonstrates a droop going on for 4 cycles. Gadgets/handle down time, impact on item quality, disappointment/breakdown of client hardware and related scrap cost, tidy up costs, support and repair costs and so on.
Swell: RMS increment in AC voltage at power frequency from half of a cycle to a few moments' length. Figure 1.4 demonstrates a swell of 2.5 cycles.
Noise: Electrical noise is undesirable electrical signs that create undesirable impacts in the circuits of control systems in which they happen. Figure 1.5 demonstrates a case of noise in a 480-V control wiring because of exchanging reverberation.

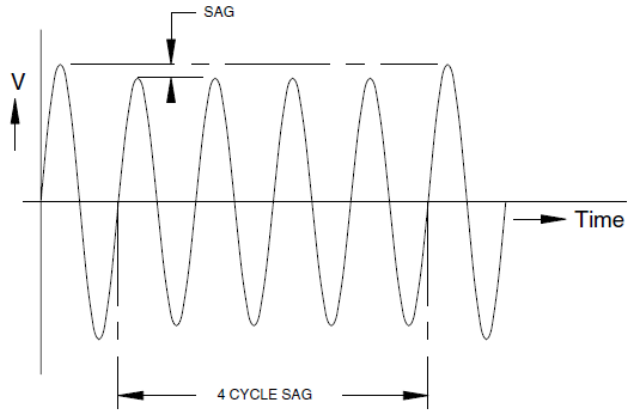

Fig- 3: Voltage sag

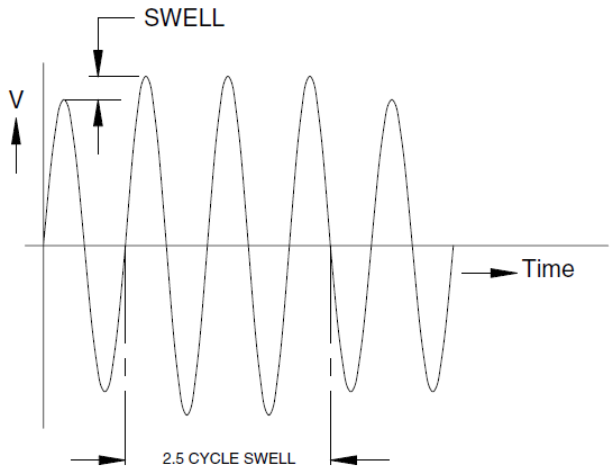

Fig-4: Voltage swell

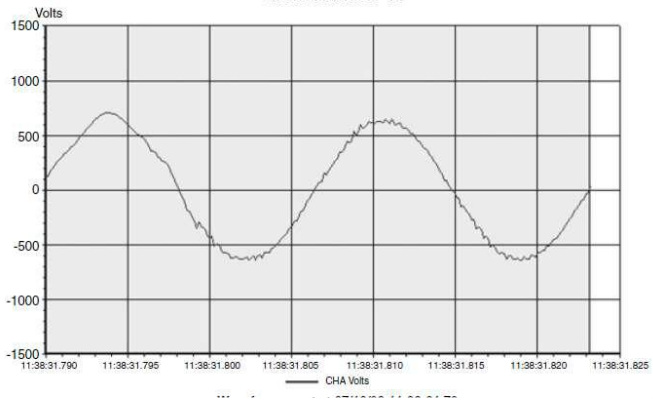

Fig-5: Noise

Symphonious streams in dispersion framework can bring about consonant mutilation, low power consider and different misfortunes and also warming in the electrical gear. It likewise can bring about vibration and clamor in machines and glitch of the delicate hardware. There are diverse approaches to improve control quality issues in transmission and dissemination frameworks. The answer for enhance the power quality at the heap side is of extraordinary imperative when the creation forms get more convoluted and require a greater risk level, which incorporates points jump at the chance to give vitality without interference, without consonant mutilation and with strain direction between extremely contract edges. The devices that can fulfill these requirements are the Custom Power; a concept that we could include among the FACTS, but that is different to them because of their final use.
Overview of the classification of FACTS Devices:
The FACTS innovation has a gathering of controllers, that can be utilized independently or coordinated with different controls installed in the network, thus permitting to profit better of the network's characteristics of control. The FACTS controllers offer an awesome opportunity to direct the transmission of substituting current (AC), expanding or reducing the power stream in particular lines and reacting promptly to the dependability issues. The capability of this innovation depends on the likelihood of controlling the course of the power stream and the capacity of associating systems that are not satisfactorily interconnected, giving the likelihood of exchanging vitality between far off operators.

FACTS DEVICES	ATTRIBUTES TO CONTROL
Synchronous Static Compensator (STATCOM)	Voltage control, compensation of VAR´s, muffling of oscillations, Stability of voltage
Synchronous Static Compensator (STATCOM with storage)	Voltage control and stability, compensation of VAR´s, muffling of oscillations, transitory, dynamics and of tension stability
Static Synchronous Series Compensator (STATCOM without storage)	Current control, muffling of oscillations, transitory, dynamics and of voltage stability, limitation of fault current
Unified Power Flow Controller (UPFC)	Control of active and reactive power, voltage control, compensation of VAR´s,

	muffling of oscillations, transitory, dynamics and of voltage stability, limitation of fault current
Interline Power	Control of reactive power, voltage.
Back to Back (BtB)	control, stifling of oscillations, transitory, dynamics and of voltage stability

Table-1: Facts devices

STATCOM

In 1999 the principal SVC with Voltage Source Converter called STATCOM (static compensator) went into operation. The STATCOM has a trademark like the synchronous condenser, yet as an electronic gadget it has no inactivity and is better than the synchronous condenser in a few routes, for example, better flow, a lower speculation cost and lower working and support costs. A STATCOM is work with Thyristors with kill capacity like GTO or today IGCT or with more IGBTs. The static line between the present confinements has a specific steepness deciding the control trademark for the voltage. The upside of a STATCOM is that the receptive power arrangement is free from the genuine voltage on the association point. This can be found in the chart for the most extreme streams being autonomous of the voltage in contrast with the SVC. This implies,

notwithstanding amid most extreme possibilities, the STATCOM keeps its full capacity. In the conveyed energy part, the utilization of Voltage Source Converters for lattice interconnection is regular practice today. The following stride in STATCOM improvement is the blend with vitality stockpiles on the DC-side. The execution for power quality and adjusted system operation can be enhanced significantly more with the blend of dynamic and responsive power.

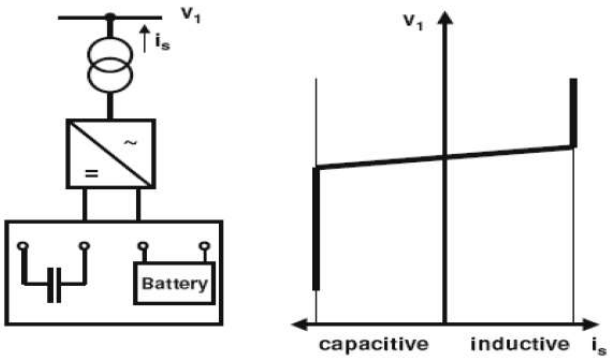

Fig -6: STATCOM structure and voltage / current characteristic

STATCOMs depend on Voltage Sourced Converter (VSC) topology and use either Gate- Turn-off Thyristors (GTO) or Isolated Gate Bipolar Transistors (IGBT) gadgets. The STATCOM is a quick acting, electronic likeness a synchronous condenser. In the event that the STATCOM voltage, Vs, (which is relative to the dc transport voltage Vc) is bigger than transport voltage, Es, then driving or capacitive VARS are created. In the event that Vs is littler than Es then slacking or inductive VARS are delivered. 1) Exchange of reactive power: - In the event that the yield voltage of the voltage source converter is more noteworthy than the framework voltage then the SATCOM will go about as capacitor and generate reactive power(i.e.. provide lagging current to the system) 2) Exchange of real power: - As the exchanging gadgets are not misfortune less there is a requirement for the DC capacitor to give the required genuine influence to the switches. For long length of genuine power necessity even after the essential supply fizzled move down vitality stockpiling framework (BESS) is utilized. Subsequently there is a requirement for genuine power trade with an AC framework to make the capacitor voltage consistent in the event of direct voltage control. There is likewise a genuine power trade with the AC framework if STATCOM is given an outside DC source to manage the voltage in the event of low voltage in the distribution system or in the event of issues.

3. IMPLEMENTATION

The Instantaneous Reactive Power Theory The control strategy is based on the p-q theory introduced by Akagi et al. and expanded to three-phase four-wire systems by Aredes et al. It applies an algebraic transformation (Clarke transform) of the three-phase system voltages and load currents in the a-b-coordinates to the α-β-0 coordinates. This theory is based on the transformation of three phase quantities to two-phase quantities and the calculation of instantaneous active and reactive power in this frame. ea, eb and ec, iLa, iLb and iLc are fed to the controller, and these quantities are processed to generate reference currents. The switching signals for the STATCOM is generated by comparing source current and reference current. The block diagram of the IRPT control algorithm is shown in Fig.7.

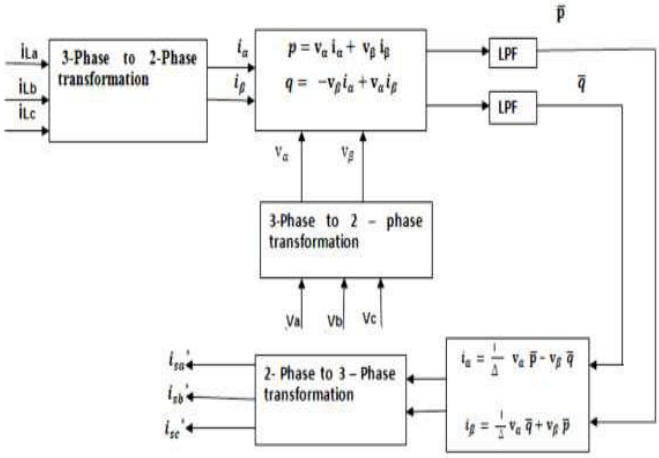

Fig-7: Block diagram of IRPT control algorithm

The three phase voltages and currents are transformed in to two phase voltages and currents as follows:

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

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\sqrt{\frac{3}{2}} & \sqrt{\frac{3}{2}} \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix}$$

$e_\alpha i_\alpha$ and $e_\beta i_\beta$ are the voltage and current along α-β axis

The conventional instantaneous active power on the three-phase circuit can be defined as follows

$$p = e_\alpha i_\alpha + e_\beta i_\beta$$

Where p is equal to the conventional equation:

$$p = e_a i_a + e_b i_b + e_c i_c$$

The conventional instantaneous reactive power on the three-phase circuit can be defined as follows:

$$q = e_\beta i_a - e_a i_\beta$$

Instantaneous active and reactive power in matrix is

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} e_\alpha & e_\beta \\ -e_\beta & e_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

The α-β currents can be obtained as

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{1}{4} \begin{bmatrix} e_\alpha & -e_\beta \\ e_\beta & e_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

$$Where\ \Delta = {e_\alpha}^2 + {e_\beta}^2$$

The instantaneous active and reactive powers p and q can be decomposed into an average and an oscillatory component

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

$$q = \bar{q} + \tilde{q}$$

Where $\bar{p}$ and $\bar{q}$ are the average (dc) part $\tilde{p}$ and $\tilde{q}$ and are the oscillatory (ac) part of these real and reactive instantaneous powers. The dc component of active and reactive power is taken to calculate the reference current.

The reference currents in α-β co-ordinate are expressed as

$$\begin{bmatrix} i_{\alpha^*} \\ i_{\beta^*} \end{bmatrix} = \frac{1}{{e_\alpha}^2 + {e_\beta}^2} \begin{bmatrix} e_\alpha & -e_\beta \\ e_\beta & e_\alpha \end{bmatrix}$$

The reference current in three phase is,

$$\begin{bmatrix} i_{ca^*} \\ i_{cb^*} \\ i_{cc^*} \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ -\frac{1}{2} & \sqrt{\frac{3}{2}} \\ -\frac{1}{2} & -\sqrt{\frac{3}{2}} \end{bmatrix} \begin{bmatrix} i_{\alpha^*} \\ i_{\beta^*} \end{bmatrix}$$

to an average value and an oscillating value. The physical meaning of each of the instantaneous powers is:

$\bar{p}$ average value of the instantaneous real power p. Corresponds to the energy per time unit transferred from the source to the load, in a balanced way through the 3 phases;

$\tilde{p}$ Oscillating value of the instantaneous real power. It is the energy per time unity that is exchanged between the power source and the load, through the 3 phases;

$\bar{q}$ The instantaneous imaginary power, q. Corresponds to the power that is exchanged between the phases of the load. This segment does not suggest any transference or trade of vitality between the power supply and the heap, however, is in charge of the presence of undesirable streams infer any transference or trade of vitality between the power source and the heap;

The STATCOM based current control voltage source inverter infuses the current into the framework in a manner that the source current is without consonant and their stage edge as for source voltage has a fancied esteem. The infused current will counterbalance the responsive part and symphonious part of the heap and enlistment generator current, in this manner it enhances the power figure and the power quality. To achieve these objectives, the network voltages are detected and are synchronized in creating the present summon for the inverter. The proposed matrix associated framework is executed for power quality change at point of common coupling (PCC).

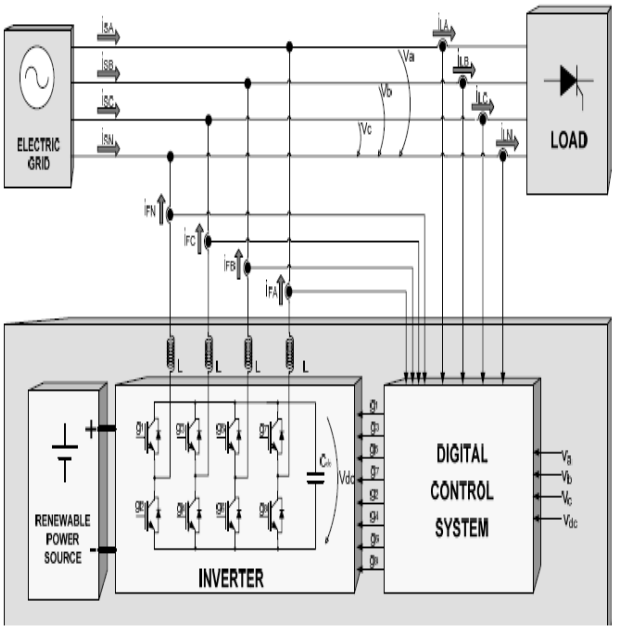

Fig- 8: Block diagram of the three-phase four wire Shunt Active Power Filter in the electric system.

The power stage of the Shunt Active Power Filter consists of a standard two-level Voltage Source Inverter with four legs, that uses IGBTs. The capacitor voltage can be kept constant by the renewable energy sources. If there is no energy available from these sources, the control algorithm changes and the energy required to maintain this voltage constant is drained from the electric grid. The inductors (L) are used to connect the inverter to the electric grid. The controller requires the three system voltages (va, vb, vc), the dc link voltage (Vdc), the four load currents (iLa, iLb, iLc, iLn), and the four inverter currents (ifa, ifb, ifc, ifn). When the Shunt Active Power Filter is connected, the source currents (isa, isb, isc), become balanced and sinusoidal, and the neutral source current (isn) becomes practically zero. The modulation technique used to drive the IGBTs is the Periodic Sampling, which is a very simple technique that establishes an upper frequency limit, but does not work with a fixed switching frequency.

4. METHODOLOGY

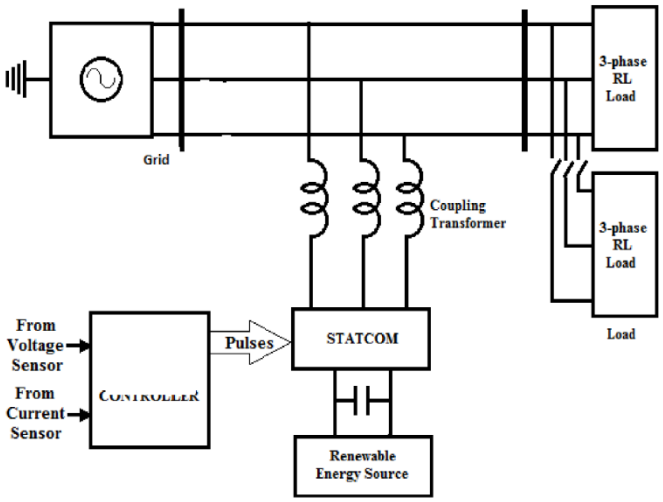

Fig- 9: Schematic of the three-phase grid system with the STATCOM Interface for renewable energy source

The STATCOM is a power hardware gadget in view of the rule of infusion or retention of responsive current at the purpose of basic coupling (PCC) to the power organizes. The primary favorable position of the STATCOM is that the remunerating current does not rely on upon the voltage level of the PCC and in this manner the repaying current is not brought down as the voltage drops. Substitute purposes behind inclining toward a STATCOM as opposed to an SVC are general overwhelming helpful characteristics, speedier execution, tinier size, cost diminish and the ability to give both dynamic and responsive power, in this way giving versatile voltage control to power quality change. Exactly when a renewable imperativeness source is used with power electronic interface, the prerequisite for the usage of additional converters and power shaping supplies rises. The inconveniences of using these additional circuits are high trading setback, extended costs and a bulkier system; in this manner the proposed plot replaces the prerequisite 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 IRPT 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.9.

CONCULSAION

This project presents the grid connected renewable energy system for power quality improvement by using STATCOM. The power quality problems, its consequences and their mitigation techniques are presented here. In this proposed plan to wipe out the symphonious substance of the heap current the STATCOM control framework is utilized so that power quality is kept up for the purpose of normal coupling. What's more, hysteresis current control plot in the STATCOM is utilized for the quick element reaction. It likewise keeps up voltage and current on a stage. Instantaneous reactive power theory (IRPT) has been developed and simulated with STATCOM interface for renewable energy source. The prove that power factor correction, reactive power compensation achieved by the instigation IRPT control algorithm. 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.

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