Power Quality Improvement for Stable Operation in Renewable Hybrid Power System using Sapf with Icosϕ Control Technique

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Abstract Nowadays Power quality is a extremely main issue. Switching actions of power electronics devices draws reactive power, which causes distortion in current waveform, resulting in harmonics which further leads to capacitor failure, resonance problem and power factor performance etc. Therefore the harmonics are eliminated and the reactive power is compensated in the power supply in the grid side. Passive filters were previously used for removal of harmonics, but due to large resonance problem and effect of source impedance on performance it was dropped.

In the proposed model, VSI used as Shunt Active Power Filter is proposed to design as per work producing component of basic current of load (ICosϕ) for providing to eliminate distortion of a sinusoidal waveform by waveforms of different frequencies and power produced by non-work producing component reparation as requested by reactive load drawn non-sinusoidal current from sinusoidal supply. Control circuit of Voltage Source Inverter provided to improve quality of power is performed for various active functioning conditions under non-linear reactive loads.

MATLAB / Simulink simulation tool is used to obtain this result. The obtained outputs were within the suggested IEEE-519 standard i.e. less than 5% and also the system power factor is almost unity.

Keywords – Voltage Source Inverter (VSI), Non Linear Loads, Solid State Electronics Converters, Harmonics, ICosϕ Control Algorithm.

I. INTRODUCTION

Now-a-days, the broad employ of nonlinear loads leads to a multiplicity of unpleasant event in the power system process. Quality of power is maintained by keeping desired level of voltage and current magnitudes, less distortion and free from interruptions. According to the solid state electronics converters prologue, distortion of current deviated from AC supply send to the system of power. Mostly distortion of a sinusoidal waveform by waveforms of different frequencies is produced at load side, howbeit harmonics are going in the direction of source side creating the non sinusoidal source. If sinusoidal and non-sinusoidal waveforms are superimposed, heavy injury happens in system of power.

II. PROPOSED METHODOLOGY

Tuned passive power filters are extremely effectual to eliminate the definite components of distortion of a sinusoidal waveform by waveforms of different frequencies howbeit these had some limitations like fixed reparation, resonance and very large size. To conquer these limitations active power filters are used which are fundamentally VSI or CSI so as to supply the essential reparation voltages and currents.

A SAPF produces spectrum of current harmonics which is contrary in phase with the current harmonics, it sees at the load end. Therefore harmonic and reactive currents are annulled at the supply end and the result is undistorted sinusoidal balanced currents.
III. PROPOSED ICOS CONTROL ALGORITHM

The ICosφ control algorithm is to provide harmonic, reactive power and unbalance reparation in a 3Ф system with balanced/unbalanced source and load conditions. It employs the smallest possible number of computational steps and is simple to practically implement in the system conditions like twist out of shaped and irregular alternating current source providing non-linear equipoised loads. The highly non-linear and reactive current drawn from the grid when it is providing a non-linear load such as diode bridge rectifier, thyristor converter, and alternating current voltage controller based loads. The aim of the algorithm is to limit total harmonic distortion in terms of percentage in the grid current within the limits given by IEEE standard to accomplish UPF at the grid end.

In ICosφ algorithm, the grid current at desired level is taking into consideration to be the product of ICosφ magnitude and unit amplitude sinusoidal in phase with the grid voltage. The grid is needed to provide only the active part of the load current and the expectation of shunt active, 

\[ i_{la} = I_{la1} \sin(\omega t - \phi_a) + \sum_{n=2}^{\infty} I_{lan} \cdot \sin(n\omega t - \phi_an) \]

\[ = R_c (I_{la1}) + I_{mn} (I_{ln1}) + \text{harmonic components} \]

\[ i_{lb} = I_{lb1} \sin(\omega t - 120 - \phi_b) + \sum_{n=2}^{\infty} I_{lbm} \cdot \sin(n\omega t - 120 - \phi_bn) \]

\[ = R_c (I_{lb1}) + I_{mn} (I_{ln1}) + \text{harmonic components} \]

\[ i_{lc} = I_{lc1} \sin(\omega t + 120 - \phi_c) + \sum_{n=2}^{\infty} I_{lcn} \cdot \sin(n\omega t + 120 - \phi_cn) \]

\[ = R_c (I_{lc1}) + I_{mn} (I_{ln1}) + \text{harmonic components} \]

Where

\[ \phi_a, \phi_b, \phi_c = \text{phase angles of fundamental currents in a, b and c phases}; \]

\[ \phi_an, \phi_bn, \phi_cn = \text{phase angles of } n^{th} \text{harmonic currents in a, b and c phases}; \]

\[ I_{lan}, I_{lbm}, I_{lcn} = \text{three phase fundamental current amplitudes}; \]

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The active component magnitude of the fundamental load current in each phase is given by

\[ |R_c(I_{ln1})| = |I_{la1} \cdot \cos \phi_a \]

\[ |R_c(I_{lb1})| = |I_{lb1} \cdot \cos \phi_b \]

\[ |R_c(I_{lc1})| = |I_{lc1} \cdot \cos \phi_c \]

To make sure, sinusoidal balanced currents with unity power factor is being taken from the system source, the magnitude of wanted source currents can be expressed as the magnitudes of average active components with load currents at fundamental frequency in the three phases

\[ |I_{oref}| = \frac{|Re(I_{la1})| + |Re(I_{lb1})| + |Re(I_{lc1})|}{3} \]

\[ = \frac{|I_{la1} \cdot \cos \phi_a + |I_{lb1} \cdot \cos \phi_b + |I_{lc1} \cdot \cos \phi_c|}{3} \]

\[ U_a, U_b \text{ and } U_c \text{ are the phase - ground voltage of source for 3Ф in unit amplitude respectively.} \]

\[ U_a = 1. \sin \omega t \]

\[ U_b = 1. \sin(\omega t - 120^\circ) \]

\[ U_c = 1. \sin(\omega t + 120^\circ) \]

Therefore, the reference currents of source for 3Ф expressed as


\[ i_{\text{at(ref)}} = |I_s(\text{ref})| \times U_a = |I_s(\text{ref})| \cdot \sin \omega t \]

\[ i_{\text{at(ref)}} = |I_s(\text{ref})| \times U_b = |I_s(\text{ref})| \cdot \sin(\omega t - 120) \]

\[ i_{\text{at(ref)}} = |I_s(\text{ref})| \times U_c = |I_s(\text{ref})| \cdot \sin(\omega t + 120) \]  

By that, the desired currents reparation of VSI for each phase found from difference in actual current of load and desired current of source.

\[ i_{\text{a(comp)}} = I_{\text{a}} - i_{\text{a(ref)}} \]

\[ i_{\text{b(comp)}} = I_{\text{b}} - i_{\text{b(ref)}} \]

\[ i_{\text{c(comp)}} = I_{\text{c}} - i_{\text{c(ref)}} \]  

(6)

Equation (7) can be expanded as

\[ i_{\text{a(comp)}} = |I_m(i_{\text{a1}})| + |I_\text{m}(i_{\text{a1}})| + \text{harmonic components} \]

\[ i_{\text{b(comp)}} = |I_m(i_{\text{b1}})| + |I_\text{m}(i_{\text{b1}})| + \text{harmonic components} \]

\[ i_{\text{c(comp)}} = |I_m(i_{\text{c1}})| + |I_\text{m}(i_{\text{c1}})| + \text{harmonic components} \]

(7)

The ICosφ magnitude is the watthour part of load current at fundamental frequency. It is taken as phase current amplitude at fundamental frequency shifted by +90° at negative going zero crossing of phase voltage as seen in fig.4. A 2nd order low pass filter have 50 Hz as well as cut off cycle per second is provided to take out the load current at fundamental frequency for an intrinsic +90° phase shift. Here the LPF worked as a zero crossing detector (ZCD) employs to find out the negative going zero crossing of the corresponding phase voltage. The fundamental phase voltage component takes out by low pass filter before it sends to ZCD for making it resistant to any incoming voltage distortion.

The ZCD with 5% tolerance made for taken care of any oscillations on the zero crossing. The phase shifted fundamental current as a “sample” input and the output pulse of ZCD as a “hold” input goes to the “sample and hold” circuit whose output is the magnitude of ICosφ. Then the mean of number of these values in 3Ф is calculated by summing amplifier having a gain of 1/3. From the given portion of control circuit or one of the 3Ф, it obviously describes how the desired reparation currents are produced using op-amp based control circuit.

The 3Ф mains voltages used as a template for producing unit amplitude of sine waves in phase with voltages of mains. Suppose the voltages of mains are out of shape, the mains voltages fundamental components are taken out with the help of second order low pass filter and utilized as a template.

A fluctuation in voltage of dc bus capacitor of SAPF is helped to compute the extra power loss in inverter and inter-phase transformer. The corresponding amplitude of phase current is computed with the help of proportional integral and derivative (PID) controller as follows and added to the real part of the load current at fundamental frequency in each phase.

Assumption 1:

Let \( V_{\text{La}}, V_{\text{Lb}}, \) and \( V_{\text{Lc}} \) be the 3Ф balanced sinusoidal voltages at the point of common coupling (PCC)

Assumption 2:

Assume that \( V^{*}_{\text{DC}} \) is the reference dc link voltage. \( V_{\text{DC}} \) is the measured actual dc link voltage. Energy lost due to capacitor while the voltage discharging is given by

\[ \Delta E = \frac{1}{2} C_{\text{DC}} (V^{*}_{\text{DC}}^2 - V_{\text{DC}}^2) \]

By keeping constant \( V_{\text{DC}} \), the energy drawn by the SAPF from the ac mains must be equal to \( \Delta E \). ie, \( P \times T = \Delta E \), where \( P = \text{active power drawn from the ac mains} = 3/2 V_{\text{Lm}} I_{\text{Cm}} \), where \( V_{\text{Lm}} \) = magnitude of instantaneous phase voltage, \( I_{\text{La}}, I_{\text{Lb}} \text{or} I_{\text{Lc}} \) and \( I_{\text{Cm}} \) = active current component magnitude, \( I_{\text{C}} \), \( I_{\text{C0}} \) or \( I_{\text{C1}} \) (corresponding to losses).

Therefore,

\[ I_{\text{Cm}} = \frac{C_{\text{DC}} (V^{*}_{\text{DC}}^2 - V_{\text{DC}}^2)}{3 V_{\text{Lm}} T} \]

Where \( T = 2 \pi / \omega \) and \( \omega \) is the frequency of sampling.

In each phase, the component corresponding to losses is summed with the allusion compensation current magnitude. This makes sure that the SAPF losses are carefully taken by 3Ф source and DC bus voltage of SAPF is a capable of supporting oneself without outside help.

After that the allusion compensation currents for the SAPF are calculated since the dissimilarity between actual load and desired mains currents for 3Ф.

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**Fig.4: Illustration of the ICos? Algorithm**

If the load currents of three phases are in balanced condition, then the desired currents reparation is basically being the addition of watthour components in each phase.

\[ i_{\text{a(comp)}} = |I_m(i_{\text{a1}})| + |I_\text{m}(i_{\text{a1}})| + \text{harmonic components} \]

\[ i_{\text{b(comp)}} = |I_m(i_{\text{b1}})| + |I_\text{m}(i_{\text{b1}})| + \text{harmonic components} \]

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After that the allusion compensation currents for the SAPF are calculated since the dissimilarity between actual load and desired mains currents for 3Ф.
V. PROPOSED HARMONICS ALLEVIATION TECHNIQUES

Harmonic removal strategies are used to enhance the power device performance through a few goals.
- System PF improvement & reactive power compensation
- THD limit maintained in current harmonic distortion.

Therefore, several strategies are used for harmonic removal from electricity device. Several used devices are:
- Induction Reactor
- Isolation transformers
- K-Factor
- PST
- Current harmonic filters are provided to decrease harmonics in current wave inside energy tools.

Major classifications of harmonics filters are:
- Passive Power filters
- Active Power filters
- Hybrid Power filters

In the proposed model, active power filter is selected and employed for the alleviation of harmonics.

A. Active Power Filter

An active power filter produce compensating current signal by unceasingly observing the current of load by means of the assist of few set of rules including ICosφ concept, p-q concept, d-q concept, D.S.P based algorithm and many others. The compensating current generated which is employed to produce the pulse of switching & series of switching of IGBT inverter by assist the hysteresis control or some different kinds of current control. Afterwards the inverter produces necessary current harmonic for the load via charging & discharging of direct current link capacitor & sent to device via coupling transformer having a phase difference to make amends the wattless power of mains of alternating current.

Active power filters are classified into two:
- Series Active Power Filter
- Shunt Active Power Filter

Shunt active power filter is proposed and used in the proposed model for the alleviation of harmonics.

VI. HYSTERESIS CURRENT CONTROLLER

This method have been provided to correct the switching signals for MOSFET inverter by examine the similarities and differences between the current error signal and given hysteresis band. The summer output ie., error signal which is sent to hysteresis band comparator and compared with the hysteresis band, then the output of comparator is fed to AF for producing the required compensating current that go after the waveform of allusion current.

Hysteresis band comparator techniques are employed for its superb forceful movement but this cannot be done if different kinds of comparator are used. The hysteresis band consists of two limits that are top and bottom limit hysteresis band.

![Control Logic of Hysteresis Current Controller](image)

While the current tendency to go beyond the top limit band, the inverter top switch is switched off and bottom switch is switched on, therefore the current trails back in a second time to the hysteresis band. So, current be positioned inside the hysteresis band and compensating current go after the current allusion.

VII. PROPOSED SIMULATION MODEL

The proposed simulation model with ICosφ Control Algorithm for current hysteresis is shown in fig.6. For done in an instant real and wattless power control of SAPF, the real and wattless power is calculated for current and voltage of the inverter and the allusion current is created which is proportional to low pass filter with disturbance in order to get disturbed power for compensation. This disturbed power is converted into current which is compared with actual value in order to create PWM for the inverter. This difference in the A phase current generates PWM which is the first leg of the inverter and similar way for B and C phase will be generated in the second and third legs of the inverter. This compensating current will produce a sinusoidal power wave at the source side. Thus, the overall circuit acts as SAPF.
VIII. SIMULATION RESULTS

The source and the load voltage is observed to be undisturbed while the current during the non-linear load operation had a dead bit which introduced higher THD in the current waveform.

In the source side, waveform of the current is imitating as that of the load side but after the compensation the current wave in the source side has improved and it is near to sinusoidal wave thus reducing the THD to a level which is accepted by international standards as shown in the figures(7 - 9)

The simulation is carried out using MATLAB PWM techniques like hysteresis controller using ICos Control Algorithm where the THD came down to as less as 1% is in compliance with IEEE 519 standards as shown in figures 10 and 12.
IX. CONCLUSION

The proposed ICosϕ algorithm is used in 3ϕ SAPF for providing to eliminate the distortion of a sinusoidal waveform by waveforms of different frequencies and wattless power reparation as required by reactive load drawn non-sinusoidal current from sinusoidal supply. Simulation is investigated by MATLAB/ Simulink for reactive power and THD. The THD in the proposed system with SAPF is less compared to power system without SAPF. The reactive power compensation is observed while compensation has occurred in the power system, so that it is needed for the source to provide only the actual power required by the load.

X. FUTURE SCOPE

Project can be extended by generating the compensating signal using fuzzy logic and neuro fuzzy compensation. The THD can be improved by using both shunt and series compensation so that the power quality can be improved.

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