

Enhancement of Power Quality Using the Combination of Thyristor-Controlled Reactor and Shunt Active Filter

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Abstract:- This paper proposes the combined system of a thyristor – controlled reactor (TCR) and the shunt active filter for harmonic and reactive power compensation. The tuned passive filter and the TCR form a shunt passive filter to compensate the reactive power. The power system harmonics are a menace to electric power system with disastrous consequences. The line current harmonics can cause increase in losses, instability and voltage distortion. Shunt active filters have been used near harmonic producing loads or at the point of common coupling to block the current harmonics. With the diverse application involving reactive power together with harmonic compensation, passive filters are found suitable. The total harmonic distortion and compensation current are carried out in MATLAB using SIMULINK. With the increase in non-linear loads in power system, more and more filters are required. The active filters are designed and analysed to improve the power quality

Keywords:- TCR , shunt active filter, Total harmonic distortion, power quality, power quality.

I. INTRODUCTION

The supply current is distorted by the non-linear loads such as UPS, DC drives, AC drives and arc furnace etc. The growing use of non-linear and time varying loads has lead to distortion of voltage and the current wave forms and increased in reactive power demand in AC mains. Harmonic distortion is known to be source of several problems such as increased power losses, excessive heating of rotating machines, audible noise and incorrect operation of sensitive loads etc. Nowadays shunt active power filter based on the voltage source inverter is used because of its efficiency. Similarly, the thyristor-controlled reactor is used to compensate the reactive power flows in the transmission line. The Synchronous Resonance Theory and dq Transformation Theory are used to generate the fundamental components of the supply current.

II. THYRISTOR-CONTROLLED REACTOR

A linear air - cored reactor is connected in series with the anti-parallel connected thyristors is known as TCR. The TCR goal is to obtain the regulation of reactive power. The anti-parallel connected thyristor pair acts like a bidirectional switch,with the thyristor valve T1 conducting in positive half cycles and the thyristor valve T2 conducting during the negative half cycle. A firing angle of 90° is results in full thyristor conduction mode. Once the thyristor valves are fired the cessation of current occurs at its natural zero crossing , a process is known as line commutation.

The TCR thus acts like a variable susceptance. Variations of firing angle will changes the susceptance and consequently ,the fundamental current component which leads to the variation of the reactive power absorbed by the reactor because the supply voltage remains constant.

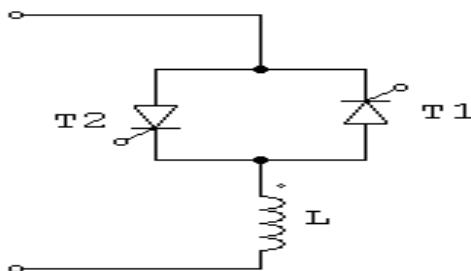


Fig. 1: Thyristor Controlled Reactor

A. Shunt Active Filter

The active power filter consists of a three-phase full-bridge voltage source pulse width modulation (PWM) inverter with an input boost inductor and a dc bus capacitor (C_{dc}). The APF sustains very low fundamental voltage and currents of a power grid, and thus, its rated capacity is greatly reduced. Because of these merits, the presented combined topology is very appropriate in compensating reactive power and eliminating harmonic currents in power system. The tuned passive filter in parallel with TCR forms a shunt passive filter (SPF). This latter is mainly for fifth-harmonic compensation and PF correction. The small-rating APF is used to filter harmonics generated by the load and the TCR by enhancing the compensation characteristics of the SPF aside from eliminating the risk of resonance between the grid and the SPF.

III. WORKING

The shunt active power filter will compensate the current harmonics by injecting the equal and opposite phase compensating harmonic current. In this case shunt active filter will act as current source injecting the harmonic component generated by the load but phase shifted by 180° . This principle is applicable to any type of load considered as harmonic source. Moreover with appropriate control scheme, the active power filter will also compensate the load power factor. In this way the power distribution system sees the non-linear load and active power filter as a ideal resistor.

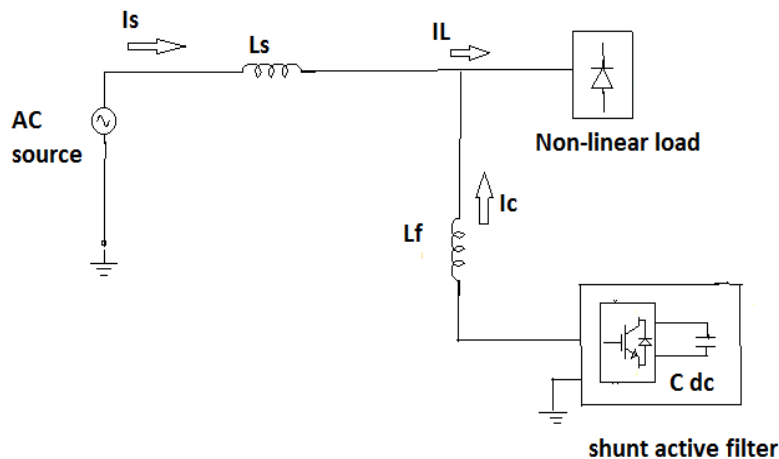


Fig. 2: Shunt Active Power Filter Configuration

A. Non-Linear Loads

The three phase diode rectifier with parallel resistor load is used as non-linear load which distorts the supply current and generate the harmonics. The supply current contains the fundamental component and harmonic component. It also consumes the reactive power from the supply line. Examples of Non-linear loads are computer system, arc furnace, UPS, AC drives, DC drives etc.

B. Mathematical Analysis

The combination of thyristor – controlled reactor and shunt active filter is used for compensating the reactive power and reducing the harmonic current of the supply line which is generated by the Non-linear loads. The supply voltage is sinusoidal form but the supply current is non-sinusoidal form due the connection of Non-linear loads in the supply line.

The supply voltage is given by ,

$$V_s = V_m \sin(\omega_1 t) \quad (1)$$

Due to the Non-linear loads, the supply current contains the fundamental components and harmonic component,

$$i_L(t) = \sum_{k=1}^{\infty} I_k \sin(k\omega_1 t + \phi_k) \quad (2)$$

$$i_L(t) = I_1 \sin(\omega_1 t + \phi_1) + \sum_{k=2}^{\infty} I_k \sin(k\omega_1 t + \phi_k) \quad (3)$$

Where

I_1 = fundamental current

I_k = k^{th} harmonic current

V_m = maximum supply voltage

Φ_k = phase angle between the supply voltage and current of the k^{th} harmonic component.

The load current is given by ,

$$i_L(t) = i_f(t) + i_h(t) \quad (4)$$

For harmonic compensation and reactive power compensation, the supply current should have the fundamental component and it should be in phase with supply voltage.

The supply current is given by ,

$$I_s(t) = I_1 \sin(k\omega_1 t) = i_f(t) \quad (5)$$

The harmonic current can be given as , $i_h(t) = i_{af}(t) + i_{pf}(t)$ (6)

The load current is given as $i_L(t) = i_{af}(t) + i_{pf}(t) + i_s(t)$ (7)

Where $i_{af}(t)$ = active filter current.

The equation (3) can be expressed as

$$i_L(t) = I_1 \sin(\omega t) * \cos \phi_1 + I_{r1} + I_d + I_{hr} \quad (8)$$

Where $I_{r1} = I_1 \cos(\omega_1 t) \sin \phi_1$ (9)

$$I_{hr} = \sum_{k=2}^{\infty} I_k \sin(k\omega_1 t + \phi_k) \text{ for } k \neq d \quad (10)$$

$$I_d = i_{pf} = I_{dm} \sin(d\omega_1 t + \phi_d)$$

The filter current is given by $i_{af} = I_{r1} + I_{hr}$ (11)

Where I_{r1} = fundamental reactive current component and I_d = dominant harmonic current

d = dominant harmonic order and I_{hr} = remaining harmonic component of the supply current

Φ = phase angle between corresponding current and supply voltage.

The zpf is the resonant filter tuned for the dominant frequency,so that it will inject the I_{pf} to the supply mains. The shunt active filter will inject the I_{hr} and the I_{r1} current so that the supply is free from the harmonics and the power factor is near to unity.

c. dq Transformation Theory :

The dq theory is based upon the time domain reference signal estimation technique. The dq components i_{std}, i_{stq} are filtered by Bessels filter.

Direct Axis Frame :

$$i_{std} = 0.67(i_{sta} \sin(\omega_1 t) - i_{stb} \sin(\omega_1 t - 2\pi/3) + i_{stc} \sin(\omega_1 t + 2\pi/3)) \quad (12)$$

Quatrature Axis Frame

$$i_{stq} = 0.67(i_{sta} \cos(\omega_1 t) - i_{stb} \cos(\omega_1 t - 2\pi/3) + i_{stc} \cos(\omega_1 t + 2\pi/3)) \quad (13)$$

This filter will filter the ripple content of dq component and it will be tranformed into a-b-c coordinates to obtain the fundamental component of the supply current.

$$I_{ra} = i_d \sin(\omega_1 t) + i_q \cos(\omega_1 t) \quad (14)$$

$$I_{rb} = i_d \sin(\omega_1 t - 2\pi/3) + i_q \cos(\omega_1 t - 2\pi/3) \quad (15)$$

$$I_{rc} = i_d \sin(\omega_1 t + 2\pi/3) + i_q \cos(\omega_1 t + 2\pi/3) \quad (16)$$

Where I_{ra}, I_{rb}, I_{rc} are the reference currents and $i_{sta}, i_{stb}, i_{stc}$ are the three phase supply current.

IV. HYSTERESIS CONTROLLER

The hysteresis controlling technique is used to generate pulse to the shunt active filter which extracts the harmonic component of the same magnitude and opposite in phase with the load current. The three phase voltage source inverter is used as active filter and IGBT switches are used in the inverter circuit for thye purpose of turn ON and turn OFF. The switching function ck of the k th leg of the converter (for $k = 1, 2, 3$) is defined as $c_k = 1$, if S_k is On and S'_k is Off

0, if S_k is Off and S'_k is On.

V. RESULTS AND DISCUSSION

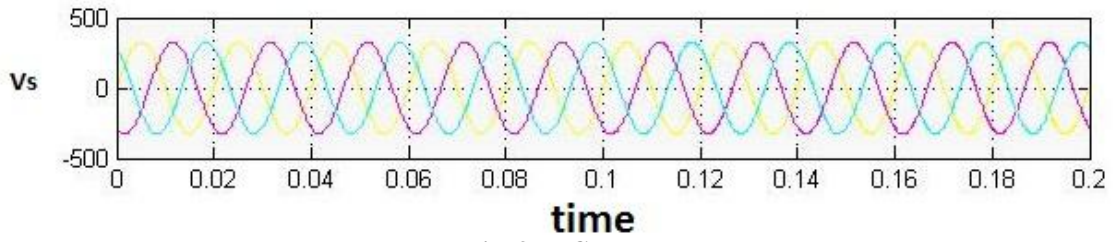


Fig. 3: TCR Voltage

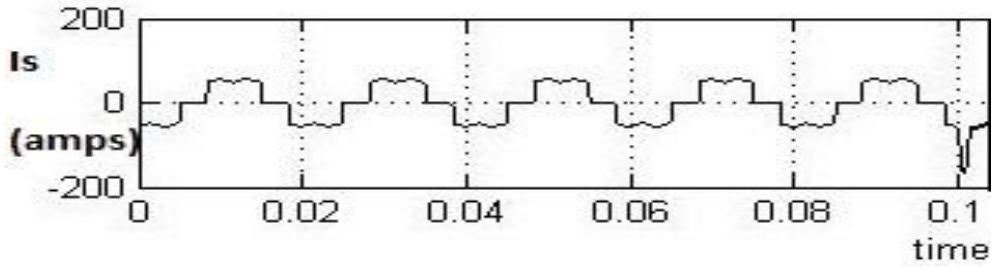


Fig. 4: Current

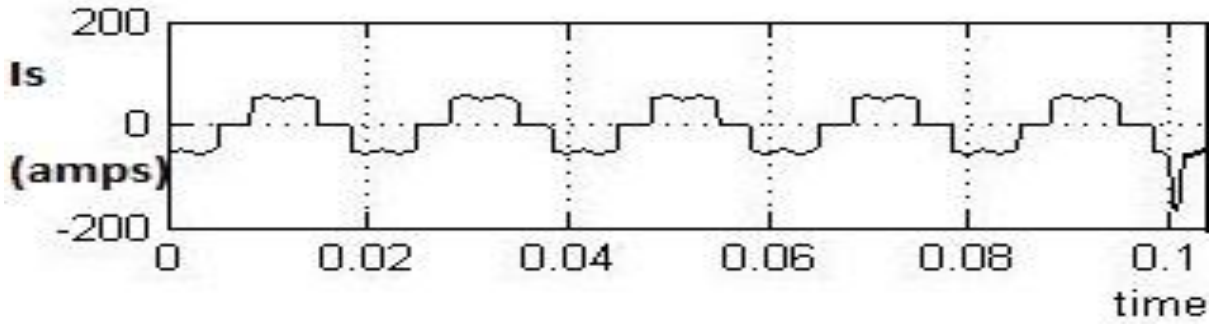


Fig. 5: supply current without filter:

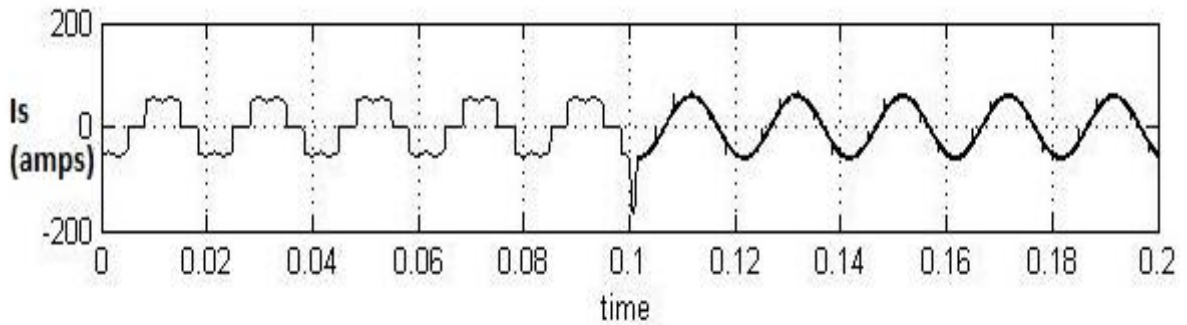


Fig. 6: supply current without filter

The passive filter is tuned for fifth harmonics and it is given by

$$f_r = 1 / 2\pi(L_p C_p)^{1/2}$$

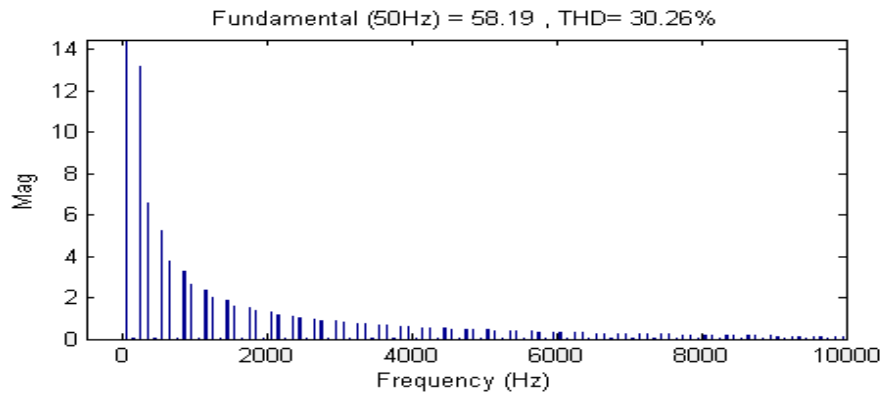


Fig. 7: THD Analysis- Without Filter

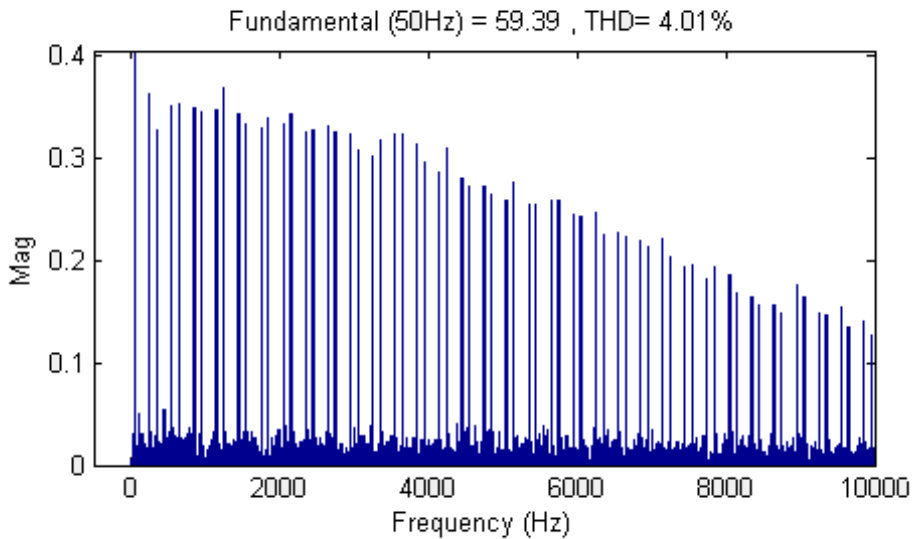


Fig. 8: THD Analysis- With Filter

The thyristor-controlled reactor and shunt active filter are simulated in MATLAB using power system blockset. The THD analysis before compensation is 30.26% . but after the compensation, the THD range is 4.01%. thus ,the reduction in the harmonics presented in the current is achieved using the combination of thyristor-controlled reactor and shunt active filter.

VI. CONCLUSION

In this paper, the combination of thyristor-controlled reactor and shunt active filter has been proposed in order to achieve the harmonic elimination and reactive power compensation. The waveforms and THD analysis are done using MATLAB simulink shows the reduction in supply current harmonics and compensation of reactive power flow in the transmission line. Thus, the Hysteresis controlled shunt active filter is used to improve the performance.

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