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A SINGLE-PHASE ACTIVE DEVICE FOR POWER QUALITY IMPROVEMENT OF LINEAR AND NON-LINEAR LOAD

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ABSTRACT

A Transformer less Hybrid Series Active Filter (THSeAF) is gives to improve the power quality in single phase systems with critical loads. This paper helps the power quality issues related to Linear and Non-linear load. The control strategy is designed to prevent current harmonic distortions of non-linear loads to flow into the utility. While, protecting sensitive loads from voltage disturbances, sags, and swells initiated by the power system. This different forms hybrid topology allowing harmonic isolation and compensation of voltage distortions could absorb or inject the auxiliary power to the system.

KEYWORDS: Hybrid series active filter, current harmonics, power quality, Nonlinear Load, real-time control.

I. INTRODUCTION

The term electric power quality is generally used to assess and to maintain the good quality of power at the level of generation, transmission, distribution, and utilization of AC electrical power. Since the pollution of electric power supply systems is much severe at the utilization level, it is important to study at the terminals of end users in distribution systems. There are a number of reasons for the pollution of the AC supply systems, including natural ones such as lightening, flashover, equipment failure, and faults. A number of customer's equipment also pollute the supply system as they draw nonsinusoidal current and behave as nonlinear loads. Therefore, power quality is quantified in terms of voltage, current, or frequency deviation of the supply system, which may result in failure of customer's equipment. Typically, some power quality problems related to the voltage at the point of common coupling where various loads are connected are the presence of voltage harmonics, surge, spikes, notches, sag, swell, unbalance, fluctuations, flickers, outages. These problems are present in the supply system due to various disturbances in the system or due to the presence of various nonlinear loads such as furnaces, uninterruptible power supplies and adjustable speed drives. However, some power quality problems related to the current drawn from the AC mains are poor power factor, reactive power burden, harmonic currents, unbalanced currents, and an excessive neutral current in polyphase systems due to unbalancing and harmonic currents generated by some nonlinear loads.

These power quality problems cause failure of capacitor banks, increased losses in the distribution system and electric machines, noise, vibrations, over voltages and excessive current due to resonance, negative sequence currents in generators and motors, especially rotor heating, dielectric breakdown, interference with communication systems, signal interference and relay and breaker malfunctions, false metering, interferences to the motor controllers and digital controllers etc.

These power quality problems have become much more serious with the use of solid-state controllers, which cannot be dispensed due to benefits of the cost and size reduction, energy conservation and other reduced maintenance requirements in the modern electric equipment. Unfortunately, the electronically controlled energy-efficient industrial and commercial electrical loads are most sensitive to power quality problems and they themselves generate power quality problems due to the use of solid-state controllers in them. Because of these problems, power quality has become an important area of study in electrical engineering, especially in electric distribution and utilization systems. It has created a great challenge to both the electric utilities and the manufacturers. Utilities must supply consumers with good quality power for operating their equipment satisfactorily, and manufacturers must develop their electric equipment either to be immune to such disturbances or to override them.

Moreover, to protect the point of common coupling (PCC) from voltage distortions, using dynamic voltage restorer function is advised. A solution is to reduce the pollution of power electronics based loads directly at their source. Although several attempts are made for specific case study a generic solution is to be explored. There exist two types of active power devices to overcome described power quality issues. The first category are series active filters including hybrid type ones. They were developed to eliminate current harmonics produced by non-linear load from the power system. Series active filters are less scattered than shunt type of active filters.

The advantage of series active filter compared to shunt type is the inferior rating of the compensator versus load nominal rating. However, the complexity of the configuration and necessity of an isolation series transformer had decelerated their industrial application in distribution system. The second category was developed in concern of addressing voltage issues on sensitive loads. Commonly known as Dynamic voltage restorer (DVR), they have a similar configuration as of Series active filter. These two categories are different from each other in their control principle. This difference relies on purpose of their application in the system

Hybrid series active filter (HSeAF) was proposed to address above aforementioned issues with only one combination. Hypothetically, they are capable to compensate current harmonics, ensuring a power factor correction, and eliminating voltage distortions at the PCC. These properties make it an appropriate candidate for power quality investments.

Advantage of the proposed configuration is that non-linear harmonic voltage and current producing loads could be effectively compensated. The THSeAF is an alternative option to conventional power transferring converters in distributed generation systems with high penetration of renewable energy sources, where each phase can be controlled separately and could be operated independently of other phases.

II. BLOCK DIAGRAM

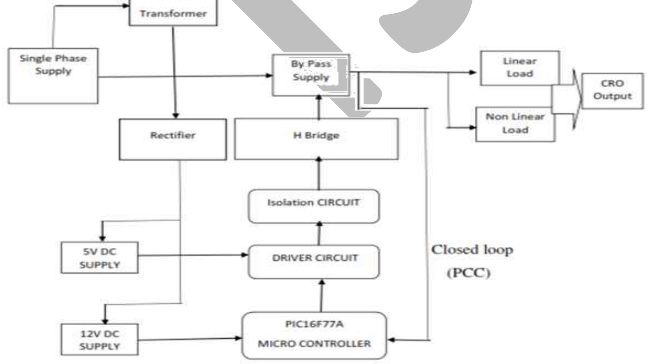

Fig. 1 Block Diagram of the THSeAF in a single-phase utility

A. H-BRIDGE:

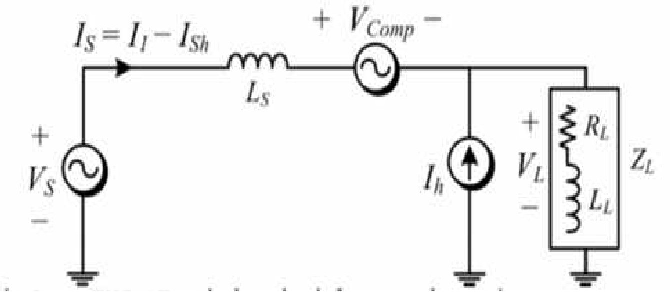

Fig.2 THSeAF equivalent circuit for current harmonics.

The series active filter represents a controlled voltage source. In order to prevent current harmonics to drift into the source, this series source should present low impedance for the fundamental component and high impedance for all harmonics as shown in Fig. 2. The use of a well-tuned passive filter is then, mandatory to perform compensation of current issues and maintaining a constant voltage free of distortions at the load terminals. The behavior of the series active filter for a current control approach is evaluated from the phasor's equivalent circuit shown in Fig. 2. The non-linear load could be modeled by a resistance representing the active power consumed and a current source generating current harmonics. Accordingly, the impedance Z_L represents the non-linear load and the inductive load.

B. DRIVER CIRCUIT:- (TLP250)

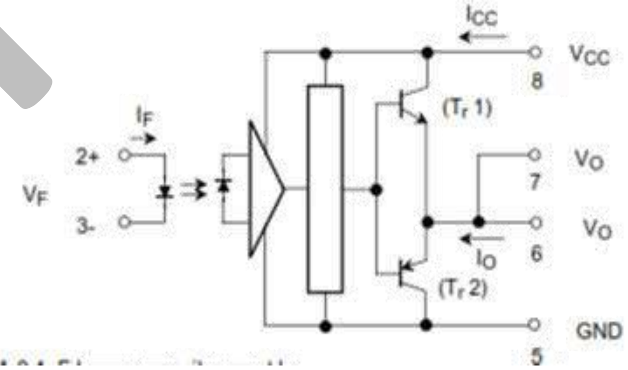

Fig. 3 Schematic diagram of Diver circuit

It can be used to amplify the 5V pulse to 12V for using transistor technology and provided isolations for using opto coupler.

C. MICROCONTROLLER:- (PIC16F77A)

It is used to generate the switching signal for H-bridge. It is used to compare source and load parameter i.e. V_L, V_s, I_s, V_{DC}, and $V_{comp.}$ When the fault is occurs in system in the form of transient, sag, swell etc then microcontroller compare the values and according to that it gives signal to microcontroller.

III. SOFTWARE IMPLEMENTATION

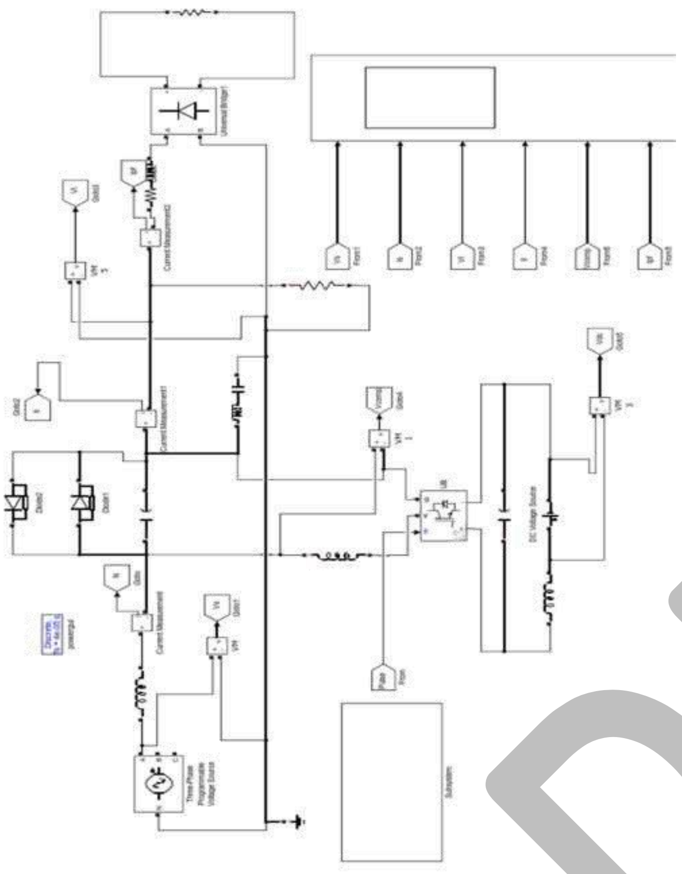

Fig. 4 Software Implementation

TABLE 1

Symbol	Definition	Value
V_s	Line phase to neutral voltage	120 V_{rms}
F	System Frequency	50 Hz
$R_{non\ linear\ load}$	Load Resistance	11.5 Ω
$L_{non\ linear\ load}$	Load inductance	20mH
P_L	Linear load power	1 kVA
Lf	Switching ripple filter inductance	5mH
Cf	Switching ripple filter capacitance	2μF
Ts	dSPACE Synchronous sampling time	40μs
f_{PWM}	PWM frequency	5 kHz
G	Control gain for current harmonics	8Ω
V_{DCref}	VSI DC bus voltage of the THSeAF	70V
PI_G	Proportional Gain (K_p), Internal gain (Ki)	0.025, 10

The THSeAF shown in Fig. 4 is composed of an H-bridge converter connected in series between the source and the load.

The SeAF represents a controlled voltage source (VSI). In order to prevent current harmonics iLh to drift into the source, this series source should present low impedance for the fundamental component and high impedance for all harmonics as shown in Fig. 2. Accordingly, the impedance Z_L represents the nonlinear load and the inductive load.

The series active filter operates as an ideal controlled voltage source (Vcomp) having a gain (**G**) proportional to the current harmonics (Ish) flowing to the grid (Vs).

$$V_{comp} = G.I_{sh} - V_{Lh} \tag{1}$$

$$V_{Lh} = Z_L(I_h - I_{sh}) \tag{2}$$

The transfer function of the compensating voltage versus the load voltage, TV_CL(s), and the source current, T_{CI} (s), are developed as follows i.e. the Relation between load voltage (**VL**) and compensating voltage (**V_{comp}**) is,

$$T_{V_{CL}}(s) = \frac{V_{Comp}}{V_L} = \frac{Z_{out}}{Z_{Load}} = \frac{L_f L_L C_{HPF} s^3 + L_f R_L C_{HPF} s^2 + L_f s}{L_f L_L C_f s^3 + L_f R_L C_f s^2 + L_L s + R_L} \tag{3}$$

A DC auxiliary source should be employed to maintain an adequate supply on the load terminals. During the sag or swell conditions, it should absorb or inject power to keep the voltage magnitude at the load terminals within a specified margin. However, if the compensation of sags and swells is less imperative, a capacitor could be deployed. Consequently, the DC-link voltage across the capacitor should be regulated as demonstrated in Fig.5.

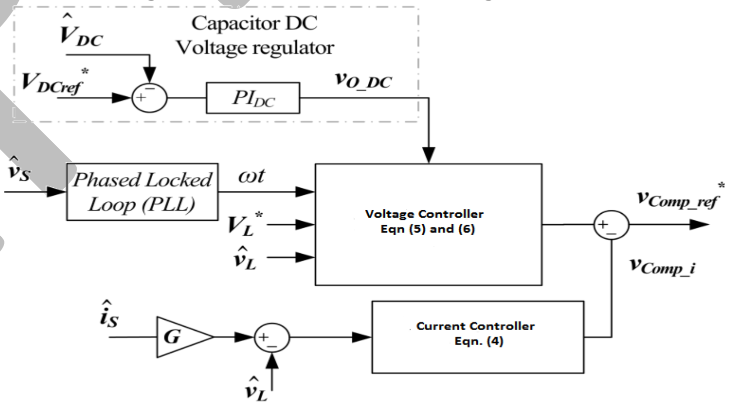

Fig. 5 Control system scheme of the active part.

The outer-loop controller is used where a capacitor replaces the DC auxiliary source. This control strategy is well explained in the previous section. The inner-loop control strategy is based on an indirect control principle. A fast Fourier transformation (FFT) was used to extract magnitude of the fundamental and its phase degree from current harmonics. The control gain **G** representing the impedance of the source for current harmonics, has a sufficiently level to clean the grid from current harmonics fed through the non-linear load.

The second PI controller used in the outer loop, was to enhance the effectiveness of the controller when regulating the DC bus. Thus a more accurate and faster transient response was achieved without compromising compensation behavior of the system. According to the theory, the gain **G** should be kept in a suitable level, preventing the harmonics flows into the grid. As previously discussed, for a more precise compensation of current harmonics, the voltage harmonics should also be considered. The compensating voltage for current harmonic compensation is obtained from 4.

$$v_{comp\_i}(t) = (-G\hat{i}_S + \hat{v}_L) - [|-Gi_{S1} + v_{L1}| \cdot \sin(\omega_S t - \theta)] \quad (4)$$

The entire control scheme for the THSeAF presented in Fig. 5 was used and implemented in MATLAB/Simulink for real-time simulations and calculation of the compensating voltage. The real-time toolbox of dSPACE was used for compilation and execution on the dsp-1103 control board. The source and load voltages together with the source current are considered as system input signals. An indirect control increases the stability of the system.

The source current harmonics are obtained by extracting the fundamental component from the source current.

$$v^*_{comp\_ref} = v_{comp\_v} - v_{comp\_i} + v_{DC\_ref} \quad (5)$$

Where the v_{DC_ref} is the voltage required to maintain the DC bus voltage constant.

$$v_{DC\_ref}(t) = V_{O\_DC} \cdot \sin(\omega_S t) \quad (6)$$

A phase-locked loop (PLL) was used to obtain the reference angular frequency (ωs). Accordingly, the extracted current harmonic contains a fundamental component synchronized with the source voltage in order to correct the power factor (PF). This current represents the reactive power of the load. The gain G representing the resistance for harmonics converts current into a relative voltage. The generated reference voltage v comp_i required to clean source current from harmonics is described in 4. According to the presented detection algorithm, the compensated reference voltage v*Comp_ref is calculated. Thereafter, the reference signal is compared with the measured output voltage and applied to a PI controller to generate the corresponding gate signals as in Fig. 6.

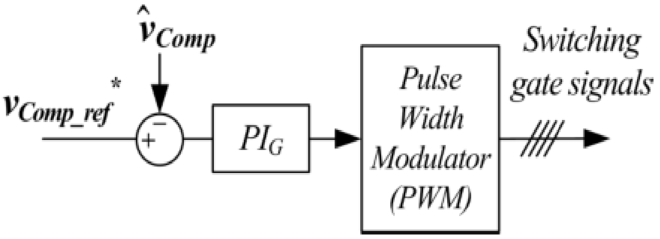

Fig. 6 Block diagram of THSeAF and PI controller.

The stability of the configuration is mainly affected by the introduced delay of a digital controller. This subsection studies the impact of the delay first on the inclusive compensated system according to works cited in the literature. Thereafter, its effects on the active compensator separated from the grid. Using purely inductive source impedance and the Kirchhoff's law for harmonic frequency components, is derived. The delay time of digital controller, large gain G and the high stiffness of the system seriously affect the stability of the closed-loop controlled system.

$$I_{sh}(s) = \frac{V_{sh} - V_{Comp} - V_{Lh}}{L_S s} \quad (7)$$

The compensating voltage including the delay time generated by the THSeAF in Laplace domain is,

$$v_{Comp} = G \cdot I_{sh} \cdot e^{-\tau s} - V_{Lh} \quad (8)$$

Considering (7) and (8), the control diagram of the system with delay is obtained as in Fig. 7

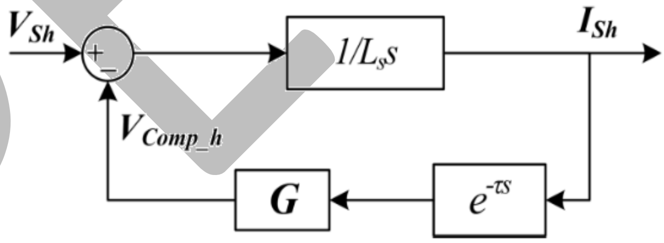

Fig. 7 The control diagram of the system with delay.

IV. RESULTS

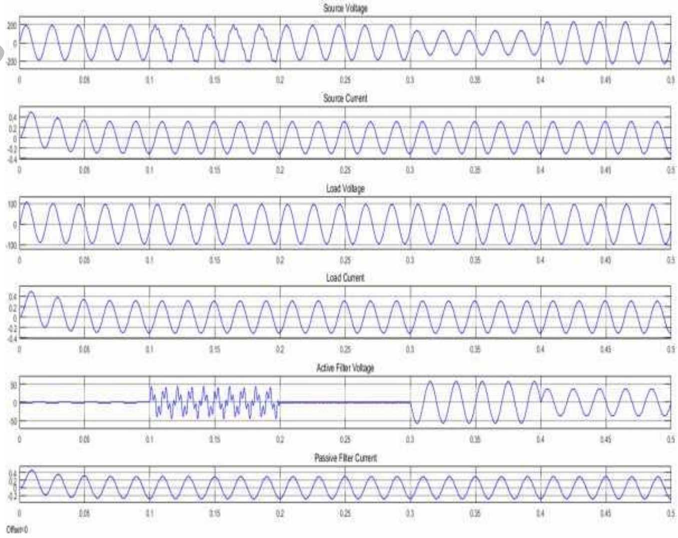

Fig.8 Simulation of the system with the THSeAF compensating current harmonics and voltage regulation. (a) Source voltage v_s, (b) source current i_s, (c) Load voltage v_L, (d) load current i_L, (e) Active-filter voltage V_{comp}, (f) Harmonics current of the passive filter i_{PF}.

V. CONCLUSION

In this simulation a Transformer less-HSeAF for power quality improvement was developed. The simulation highlighted the fact that with the ever increase of non-linear loads and higher demands of consumer for a reliable supply. The proposed solution is that the proposed configuration could improve power quality of the system in more general way by compensating a wide range of harmonics current. Even though, it can be seen the THSeAF regulates and improves the PCC voltage. Connected to a renewable auxiliary source. This essential capability is required to ensure a consistent supply for critical loads. Behaving as high-harmonic impedance, it cleans the power system and ensures a unity power factor. The proposed transformer less configuration was simulated. It was demonstrated that this active compensator responds properly to source voltage variations by providing a constant and distortion-free supply at load terminals. Furthermore, it eliminates source harmonic currents and improves power quality of the grid without the usual bulky and costly series transformer.

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