ACTIVE FILTER FOR HARMONIC MITIGATION FOR MAGNET POWER SUPPLIES OF INDUS-II

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Abstract

Power supplies used for powering of magnets in INDUS-I and INDUS-II use different type of power converters including SMPS and thyristorised power converters. Though considerations are given to keep the harmonic loading on a.c. mains low while designing these power supplies and selecting a suitable power converter for the required power, still they give a significant amount of harmonic loading on a.c. mains. In all the high power d.c. power supplies, wide variation in operating point leads to a considerable amount of reactive power generation and harmonic loading on ac mains.

In this work a study has been performed to know the variation of reactive power with time on some of the d.c. power supplies of INDUS-II. Various options to improve the power factor has been studied and their advantages & limitations for accelerator magnet power supplies have been highlighted. A combined system of a shunt passive and small rated series active filter has been proposed. The compensation principle is described and filtering characteristics are discussed in detail. A scaled down prototype of proposed series active filter has been developed in lab and experimental results produced.

INTRODUCTION

Harmonic interference problems generated by bulk thyristor converters become increasingly serious as they are widely used in industrial applications in general and accelerator power supplies in particular. So far shunt passive filters have been widely used to tackle this problem. However shunt passive filters have many problems to discourage their application. [6] Filtering characteristics of a shunt passive filter are determined by the impedance ratio of source and shunt passive filter. Fig 1 below shows the equivalent circuit of a shunt passive filter.

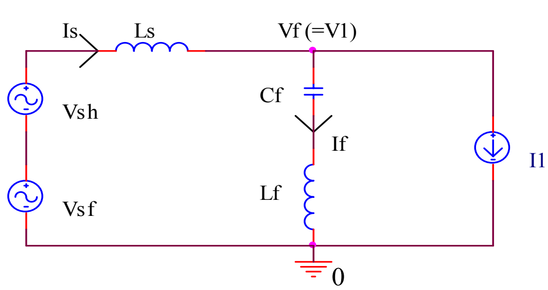

Figure 1: Basic principle of shunt passive filter

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Therefore shunt passive filters have following problems.

(i) The source impedance, which is not accurately known and varies with the system configuration, strongly influences filtering characteristics of the shunt passive filter.

(ii) Shunt passive filter may fall in series resonance with source impedance for harmonic voltages in source voltage.

(iii) There is a possibility of parallel resonance between source impedance and shunt passive filter at a specific frequency at which even harmonic amplification may take place.

To solve the preceding problems of shunt passive filters, shunt active filters using PWM inverters have been used in recent years. A shunt active filter is controlled in such a way so as to actively shape the source current into sinusoid by injecting the compensating current. Fig 2 below shows the working principle of a shunt active filter.

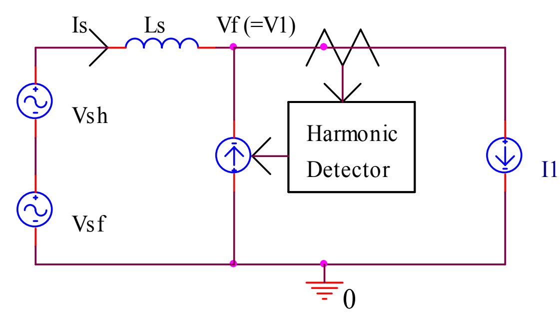


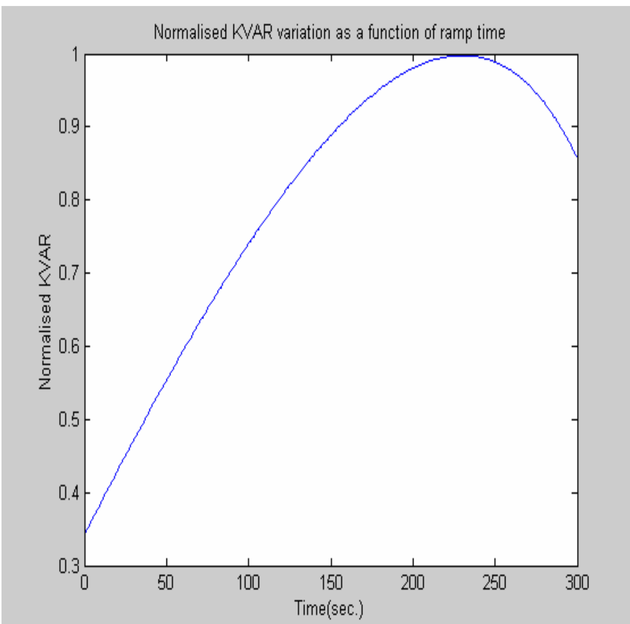
Figure 2 : Basic principle of shunt active filter

Difficulty in realising a large rated PWM current source inverter, high initial cost & low efficiency as compared to shunt passive filters and possibility of importing harmonics from other harmonic producing loads are the serious practical problems with the use of shunt active filters [5].

PROPOSED SCHEME

Conventional shunt passive and active filters have the aforementioned problems, which make their practical application difficult. As is already pointed out, filtering characteristics of a shunt passive filter partially depend on the source impedance which is not accurately known and is predominantly inductive. The impedance of the shunt passive filter should be lower than the source impedance at a tuned frequency to provide the attenuation required. Source impedance can be increased and thereby filtering characteristics of a shunt passive filter can be improved by inserting an active impedance in series with the source impedance. Also series and parallel resonances in the shunt passive filter, which are partially caused by the inductive source impedance, can be eliminated by inserting an active impedance. This active impedance can be implemented by a series active filter using voltage source PWM inverter in automatic feedback loop.

The proposed scheme can supply a fixed amount of capacitive VARs only and the same has to be taken into account while designing the passive filters. Fig 4 below depicts the typical variation of reactive power for energy ramp time of 5 minutes in INDUS-II. Passive filters can be designed to supply an average KVAR between two extremities to maintain a reasonably good power factor over full range of operation.



System Configuration and lab prototype

Figure 3 shows a system configuration of the proposed approach to harmonic isolation for generic harmonic producing loads. Figure 4 shows a detailed circuit of series active filter on a per phase basis. A small rating single phase diode rectifier is connected on dc side of inverter, supplying the energy corresponding to the switching and conducting losses in the inverter. The purpose of the transformer is not only to isolate the PWM inverter from the power system, but also to match the voltage and current rating of the PWM inverter with that of the power system.

The harmonic current flowing in the source which is produced because of, both the load harmonic current Ilh and the source harmonic voltage Vsh , is given as :

$Ish = Ilh*Zf/(Zs+Zf+Rsf) + Vsh/(Zs+Zf+Rsf)$ ....(1)

$Ish \approx 0$ if $Rsf >> Zs,Zf$ .... (2)

Zs and Zf are source and passive filter impedances respectively. Rsf is the series active impedance introduced by series active filter. Thus a series active filter should maximise Rsf within practical limits to realise the approximation of equation 2. A lab prototype has been developed to test the effectiveness of series active filter in reducing harmonics. A 500VA 1ph diode rectifier, followed by LC filter and resistive load, has been taken as the source of harmonics. A 1ph PWM voltage source inverter has been designed to work as series active filter. The series active filter works on the harmonic current information of 1ph rectifier in an automatic feedback loop to deliver a suitably large value of Rsf as required by equation (2).

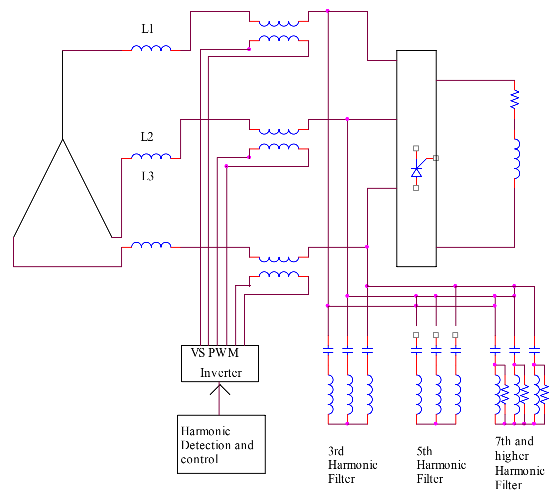


Figure 3: Harmonic mitigation using a combination of series active and shunt passive filters.

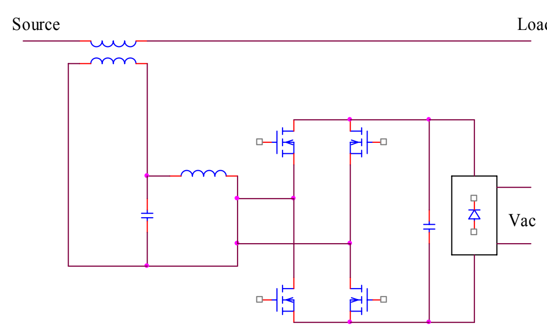


Figure 4 : Detailed circuit configuration of a series active filter on per phase basis

EXPERIMENTAL RESULTS

Figures 6,7 and 8 below shows the results of the proposed scheme on a lab prototype in three different conditions of operation. Results produced are for a source impedance of nearly 4%.Prototype used tuned filters for 3^{rd} and 5^{th} harmonics and a common filter for all higher order harmonics. Measured total harmonic distortion was found to be nearly 6.0%. 3rd harmonic was found to be nearly 3.75%. For 3ph converters which do not load the line with 3rd harmonic currents, THD figures will be much better. This figure will improve further if a tuned filter is used for 7th harmonic also. Here active filter control works on the information of line current harmonics only. Source voltage was assumed to be purely sinusoidal. A DSP based control to retrieve the information of harmonics using the generalised theory of instantaneous reactive power in 3ph. circuits [1] is under development and results with the same are expected to be still better.

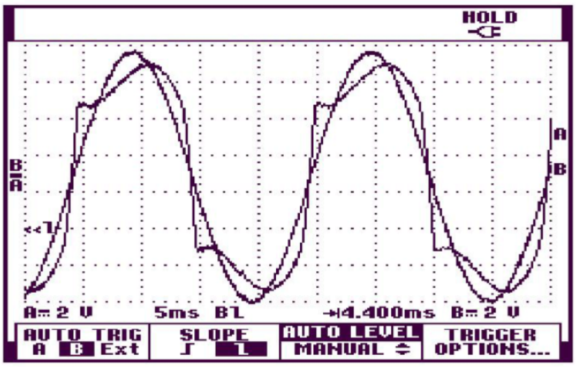


Figure 6: Load current on 1ph mains (Ch. A) and it's fundamental component (Ch. B)

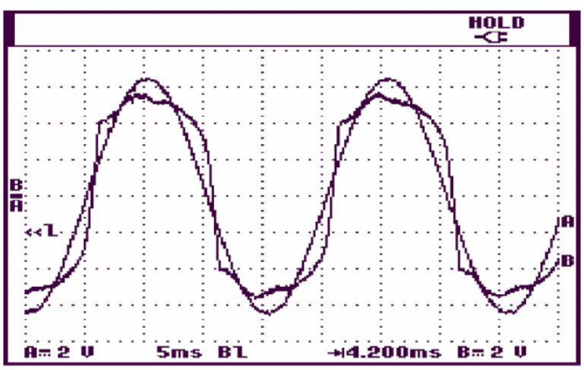


Figure 7: Load current on 1ph. mains (Ch. B) and it's fundamental component (Ch. A) with passive filter only.

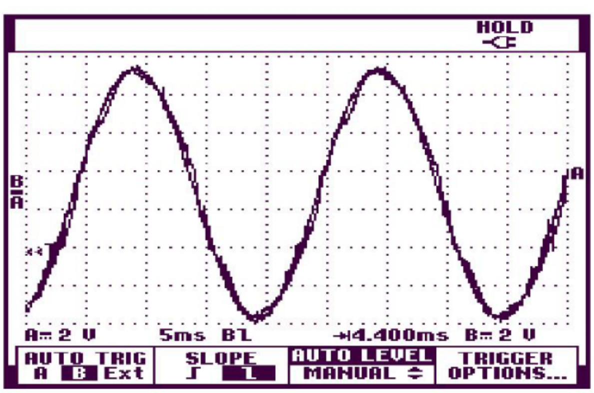


Figure 8: Load current on 1ph. Mains (Ch. B) and it's fundamental component (Ch. A) with both active and passive filters in operation

CONCLUSION

A combined system of shunt passive and small rated series active filter has been proposed in this paper. The compensation principle here is quite different from conventional shunt and series active power filters. The proposed scheme gives better filtering characteristics and offers lower initial and running cost. The proposed scheme is far superior in efficiency to conventional shunt active filters. However this scheme has few limitations listed below.

(i) This scheme in the present form can not supply variable reactive VARs. In our case reactive VARs vary in a wide range because of wide variation in displacement factor during the range of operation. Depending upon the design of passive filter, the present scheme at the most can improve the power factor in general across the range of operation. To get better results, switched capacitor scheme can be used but effect of the same on the dynamics of active filter should be studied.

(ii) Being a series element, active filter should have very reliable protection against overloads and short circuits.

Thus we see that a series active filter works as a harmonic isolator while a shunt active filter works as a harmonic compensator. The combination of shunt passive filter and a small rated series active filter is an efficient, simple and economic alternative to shunt active filters.

ACKNOWLEDGEMENT

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