Optimisation of Switches in Power Conditioner for Harmonic Compensation and Sag Mitigation

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Abstract— Power conditioner provides power output with reduced electrical pollution in it. Various configurations can be formed using different converter & filter topologies. In this study, a 12- switch conditioner is compared with an 8-switch power conditioner for current reduction & compensation and voltage sag mitigation and the results are investigated. The architecture of the power controller showcases a transformer-less hybrid design filter based on 4-switch 2-leg inverter and a 6-switch dynamic voltage restorer. The test makes an effort to optimise the use of switches in power conditioner without affecting the output and thus resulting in reduction of switching losses.

Keywords— *Power Quality, Voltage Sag, Total Harmonic distortion (THD), Switching Losses, Power Filters*

I. INTRODUCTION

In electrical power system, power electronics devices plays an important role. In distribution system it has three aspect first one is that introduces valuable industrial and domestic equipment's, second one is that creates problems, third one is that help to solve problems. Now a day's modern semiconductor switching devices such as controlled rectifiers, Uninterruptible Power Supplies (UPS), arc furnaces etc. are widely used particularly in domestic and industrial loads.

These non-linear loads create power quality problems such as voltage sag, voltage swell, voltage interruption, voltage flickers, voltage spikes, harmonics etc. Such poor power quality causes increase in power losses and other remarkable abnormalities in distribution sides. Thus, it is very important to maintain a high standard of power quality. Earlier passive filters were used to solve power quality problems. However because of some limitations of passive filters, now a day's custom power devices are used to solve power quality problems in distribution side. The compensating custom power devices are used for active filtering, load balancing, power factor improvement and voltage regulating (sag/swell).There are three types of custom power devices: Distribution Static Compensator (DSTATCOM), Dynamic Voltage Restorer (DVR) and Unified Power Quality Conditioner (UPQC).

One of the most important issues related to power quality solutions is the current harmonics generated by the increasing number of nonlinear loads connected to the power grid. The shunt active power filter, consisting basically of a voltage source inverter with a large capacitor on its dc link, is considered a well-established solution to reduce the current harmonics to the recommended standard limits. The major drawback of shunt active power filters is the high-power rating components required to compensate high peak harmonic currents and their associated costs. An alternative, called hybrid filter mixes low-power-rating active filters with passive filters, aiming cost reduction.

Another important issue related to power quality is the short duration voltage variations, which is the most, frequent and significant disturbances present in the power grid, and they are largely responsible for unplanned shutdowns in industry. It is often caused by system faults, aiming a cost reduction, this paper presents an eight-switch power conditioner for current harmonic compensation and voltage sag mitigation derived from the nine-switch converter. The proposed power conditioner presents a transformer-less hybrid filter based on a four-switch two-leg inverter and a six-switch DVR. Thus, it is expected that the proposed conditioner presents good harmonic compensation capability and voltage sag mitigation with the advantage of having a reduced number of switches with respect to a conventional back-to-back converter. Performance of industrial processes depends on quality of electric power supplied to it. Automated systems are gaining popularity to improve production, but such systems operates in a precise flow of instruction through microcontroller. Any power fluctuation can damage or stop the process, as these are sensitive to electrical disturbances. The significant increase in the nonlinear loads such as diodes and thyristors rectifiers, connected to the electric system contributes to increasing pollution by harmonic content in the grid, affecting sensitive loads.

II. POWER QUALITY PROBLEM AND MITIGATION

Any sudden or unwanted variation in voltage, current or frequency, which disturbs the operation of a device is termed as power quality problem [1]. The major power quality issues in grid are voltage sags, voltage swells, harmonic distortion, unbalance voltages, flickers and frequency variations. [2] A major problem in power quality scenario is the current harmonics created by the use of nonlinear loads. A waveform distortion is considered harmonic when it has a fixed frequency overlapped with frequencies which are multiples of the fundamental. It occurs in nonlinear loads as the currents absorbed by them have frequency components different to the fundamental. [3] IEEE Std. 519, sets allowable limits to the injection of harmonics on the electric grid. The most widely used degree to measure the harmonic volumes in any waveform is the total harmonic distortion (THD). [4] Short duration voltage variations, responsible for unplanned shutdowns in industry, is also a major power quality issue. According to the IEEE std. 1159-1995, a voltage sag is a decrease in voltage between 10% to 90% of rated voltage, in the fundamental frequency range, which may be lasting half cycle of the grid frequency to one minute. [5] Typically, voltage sags are caused by sudden increases in grid currents, due to the starting of large motors, large loads input or large generating blocks output and faults (short circuits) at remote points in the grid [6].

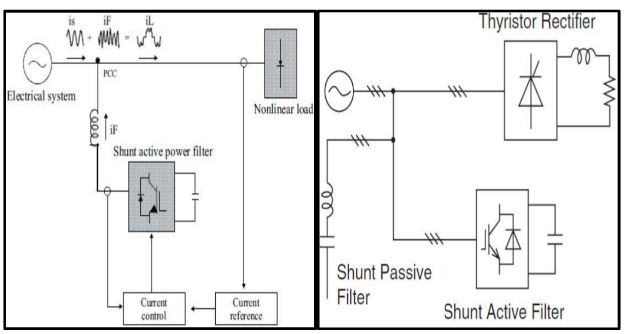

Fig 1- Shunt Active & Hybrid Filter

Based on the various power quality issues faced by electrical systems, a number of components or circuits are designed to mitigate different issue. The design of shunt active power filter, is shown in figure 1, consisting basically of a voltage source inverter with a high rated capacitor commissioned on its dc-link, is used to reduce the current harmonics to the recommended limits as per ideal standards [7]. A drawback affecting the use of shunt active power filters is the large power rating of the devices required for compensating high peak values of harmonic currents and it increases cost [8]. A hybrid filter, as shown in figure 1, mixes low power value active filtering circuit with passive filter circuit, allowing a fall in cost [9]. The LC filter absorbs limited harmonic currents created by the nonlinear loads connected to it, whereas the active filter improvises the real filter characteristics of the LC connected filter. [10] The dynamic voltage restorer (DVR) is a device invented for compensation of voltage sags and swells. It has been modified to perform tasks like controlling the transient voltage level as well as harmonics in voltage, protection of highly sensitive loads from unplanned shutdowns and voltage mal-operations due to power quality disturbances. [11]

Voltage Source Converter (VSC) functioning as a custom power devices are increasingly being used in power transmission applications to mitigate problems in power utilisation system. The series active power filter corrects problems in voltage waveform distortion such as injected harmonics, sudden flicker, momentous sag and swell. The shunt active power filter compensate current distortions like harmonics and phase angle displacement of the load current from the system voltage. [12]

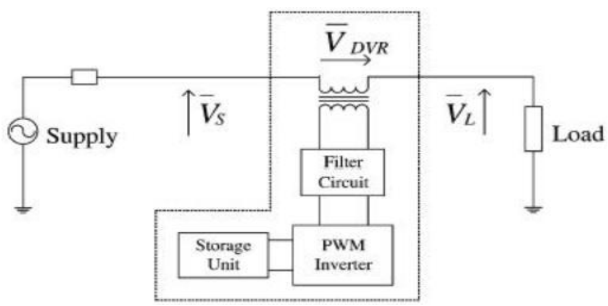

Fig 2 - Dynamic Voltage Restorer

III. TWELVE SWITCH POWER CONDITIONER

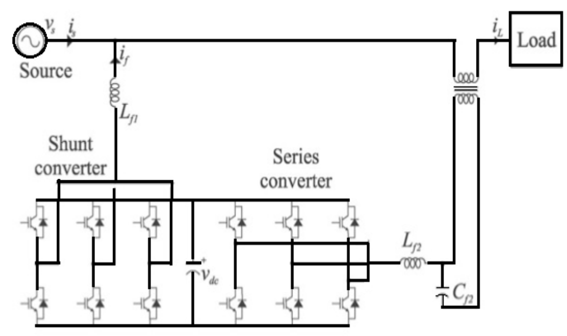

Fig 3– 12- Switch Back-to-Back Conditioner

Presently there is the necessity for advancement of power flow controllers for increase in the volume of transmission and controlling the power-flow through pre-defined stretch of transmission network. The figure describes the basic structure of 12-switch conditioner that embroils of two switching power converters connected back-to-back over a common DC-link. The series 6-switch converter provides the key function of the UPFC by voltage injection, through adjustable magnitude and phase angle over a series connected transformer. If the transmission line current licences through this voltage source, the series converter relates active & reactive power through the transmission system over the transformer. The shunt 6-switch converter is obligatory to deliver or soak-in the active power demanded by the series converter at the common DC link, i.e., it helps to keep the DC link voltage at a constant value. The circuit also generates and absorb reactive power. The shunt converter can also normalize the reactive power inoculated at bus.

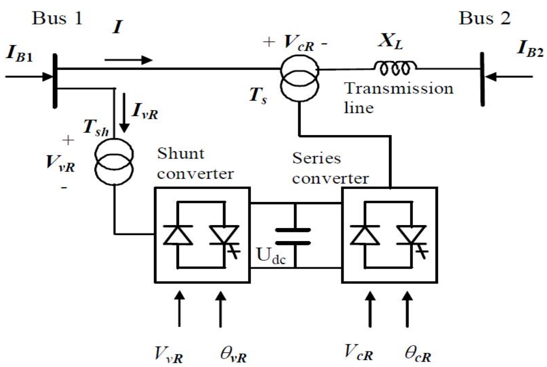

Fig 4-- Mathematical form of 12-Switch Conditioner

The complex power equation can be written as follows:

$$S=P0+PcR+PvR+j(Q0+QcR+QvR) \quad (1)$$

$$Po = \frac{V_1+V_2}{X_L+X_{CR}} \sin\delta \quad (2)$$

$$Qo = \left(\frac{1}{X_{CR}} - \frac{X_L}{X_{CR}(X_L+X_{CR})}\right)V_1^2 - \frac{V_1V_2}{X_L+X_{CR}} \cos\delta \quad (3)$$

$$P_{cR} = \frac{V_1V_{cR}}{X_L+X_{CR}} \sin\theta_{cR} \quad (4)$$

$$Q_{cR} = \frac{V_1V_{cR}}{X_L+X_{CR}} \cos\theta_{cR} \quad (5)$$

$$P_{VR} = \frac{V_1V_{cR}I_{vR}}{X_L+X_{CR}} \cos\theta_{vR} \quad (6)$$

$$Q_{vR} = \frac{V_1V_{cR}I_{vR}}{X_L+X_{CR}} \sin\theta_{vR} \quad (7)$$

IV. Eight-Switch Power Conditioner

In general, in a conditioner, the compensation for load current harmonics is done by governing shunt converter and the series converter is organized for voltage sag mitigation. The system achieves the objective at reduced cost compared to simple active filters alone at high power rated conditions. The architecture under study is an 8-switch power conditioner, expending a hybrid filter in shunt converter. The converter performs the signal input to provide compensation to the current harmonics and, during voltage sag, it increases the range of the carrier frequency dedicated to the series connected converter to inject the signal for a rated load voltage. The passive filter is tweaked to the seventh harmonic, devouring a low impedance about this harmonic and a high impedance about the switching frequency. The selection criterion for seventh harmonic compensator are [10]:

- The LC filter working at the 7th harmonic frequency is smaller and less expensive than the system working at the 5th harmonic frequency
- The 7th harmonic tuned filter grants reduced impedances at the eleventh and thirteenth harmonic frequencies comparative to the 5th harmonic tuned filter does;
- The filter characteristic of the fifth level harmonic frequency be significantly upgraded by the feed-forward control.

Replacing the traditional converter by the eight-switch converter is a doable selection, which saves four semiconductor switches, since the switches set up in the traditional converter for series compensation are less used.

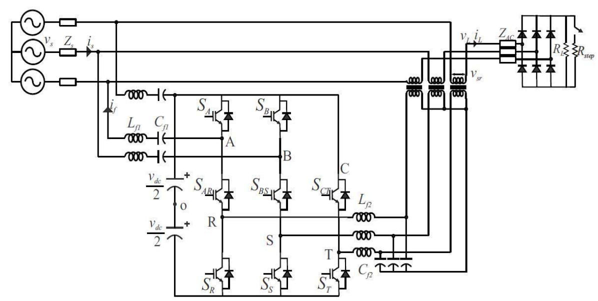
Fig 5 - Eight-Switch Conditioner Configuration

A. Operation

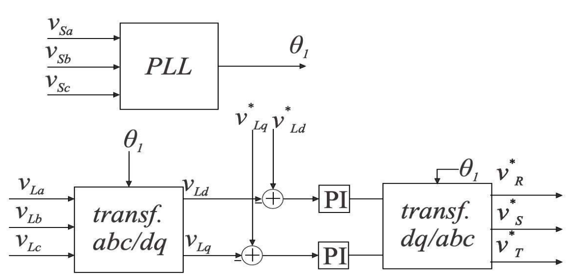

Fig 6 - Series Control Arrangement

During normal operation, the output voltages of the shunt converter are substantially greater compared to the voltages announced by the series converter. The general configuration is shown in the figure. This means that the intonation orientation is essential to the shunt converter (M_{sh}) is much larger than linked with the series converter (M_{se}). The duty cycles of switches A and R, correspondingly, can be resolute by:

$$D_A = 0.5 + v_A / v_{dc} \quad (8)$$

$$D_R = 0.5 - v_R / v_{dc} \quad (9)$$

Where, v_A, v_R is the reference voltage levied at the output terminal X, relative to midpoint connection. Directing only on converter leg, AR, it is promising to discover that switch A pedals the voltage V_{AC} as follows:

$$V_{AC} = (D_A - 1)\, V_{dc} \quad (10)$$

It should be stated here that, an inequality exists,

$$v_A \geq v_R \quad (11)$$

$$D_A \geq 1 - D_R \quad (12)$$

In leg C, it can be seen that,

$$v_c = + v_{dc} / 2 \quad (13)$$

Therefore,

$$v_{AC} + v_{dc} / 2 \geq v_R \quad (14)$$

Also, taking into account that $D_A \leq 1$, it is seen that,

$$v_{AC} \leq 0 \quad (15)$$

The condition of the intermediary switch is defined as the exclusive OR of the top and bottom switches conditions, for proper operation.

B. Series Control

As seen in figure Y, the series control has the objective of certifying rated voltages at the load terminals. To accomplish the control, the grid voltages are restrained, giving evidence for the series control and for the phase-locked loop, liable for engendering the reference angle for the conditioner. The load voltages are distorted to (dq) so the regulator actions using PI controllers can be effective. The controller outputs of axes d and q are fetched to the natural abc reference-frame over the inverse transformation. The output reference voltages (v_R ; v_S ; v_T) are formerly normalized with respect to the voltage restrained on the dc-link, v_{dc}. Lastly, the duty cycle of the switch R of the series converter is shaped as:

$$D_{Rseries} = 1 - M_{series}\, (v_R/v_{dc} + 0.5) \quad (16)$$

M_{series} confines the amount of carrier to be used for the series control. The duty cycles are then used to engender the intonation pulses by relating with a triangular carrier. The series converter is liable for inoculating only fundamental voltages, since the projected conditioner is intended to mitigate voltage sags. Therefore, the corner frequency of the LC filter should be greater than fundamental frequency, but also well below switching frequency.

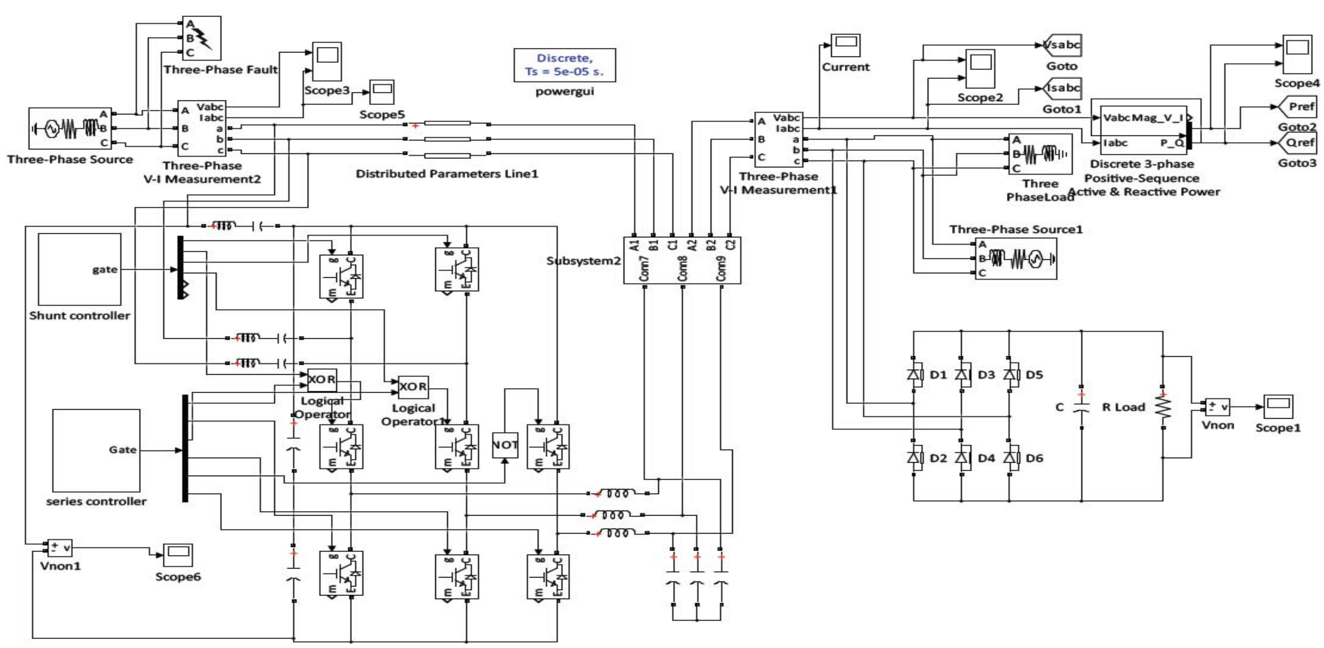

Fig.7. MATLAB model of 8-switch conditioner

C. Shunt Control

The grid current and load currents are monitored for feedback and feed-forward controls and uses of the phase-locked loop system. The hybrid filter reins the dc-link voltage. In the feedback control, the transformation abc-dq in the fundamental frequency transfigures the 3-phase grid currents into active and reactive instantaneous currents. The fundamental mechanisms in the grid correspond to the dc current and harmonic components correspond to AC. Two high-pass filters (HPF) of 1st order by cut-off frequency of 16 Hz excerpt the ac components from dq components. Then the inverse transformation dq-abc yields harmonic components requisite for compensation. Each harmonic current is augmented by gain K, by the equation:

$$v_{AF} = K \; i_{Sh} \tag{17}$$

The voltage of the dc-link is panelled by the hybrid filter. When the active filter is controlled to yield fundamental voltage in phase with the fundamental lead current of the passive filter, a real power is shaped by the current and the fundamental voltage concerns the dc-link capacitor. A PI controller is used in the control algorithm. Addition of both the outputs from the feedback and the feed - forward control is done which is used for generation of the duty cycles for semiconductor switches. On the output of the control, two line-to-line voltages are generated due to the absence of one of the switches. Generation of the duty cycles for the continuing switches can be done using these values. Thus, for AS & BS legs;

$$D_{Ashunt} = 1 + M_{shunt} \, (v_{AC} / v_{dc}) \tag{18}$$

$$D_{Bshunt} = 1 + M_{shunt} \, (v_{BC} / v_{dc}) \tag{19}$$

V. SIMULATION & RESULTS

To scrutinise the enactment of the configuration of power delivery system, a comparative simulation test was conducted in MATLAB on the model, as shown in the figure 7. After simulating the two systems and performing the FFT Analysis, we have calculated the harmonic distortion level in the circuit. The results are summarised in Table I. The simulation gives the following graphical outputs that can be related with the result table:

TABLE 1- RESULT TABLE

Parameters	12 SWITCH	8 SWITCH
Source Voltage	300V	600V
DC-Link Ref. Voltage	450 V	570V
Output Voltage	540V	370V
% THD	13.45%	3.80%

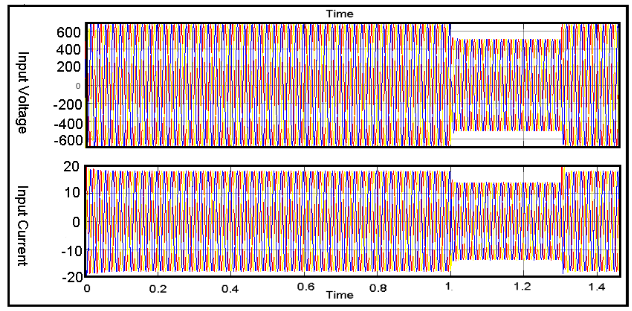

Fig 8 - Input Voltage & Current

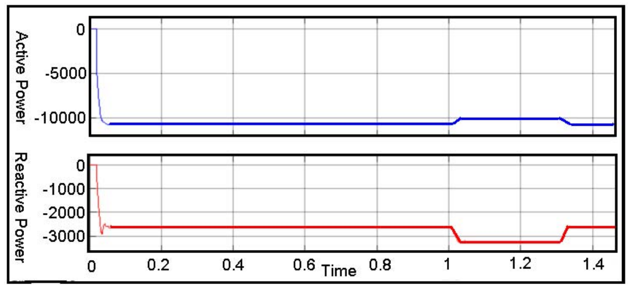

Fig 9- Active & Reactive Power Output

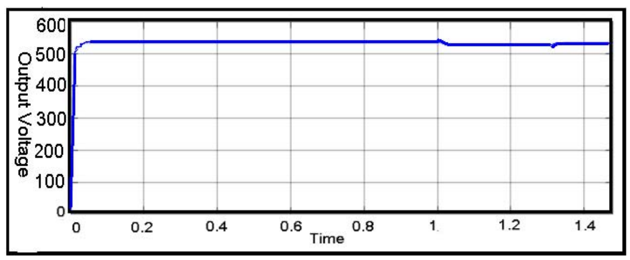

Fig 10- Output Voltage

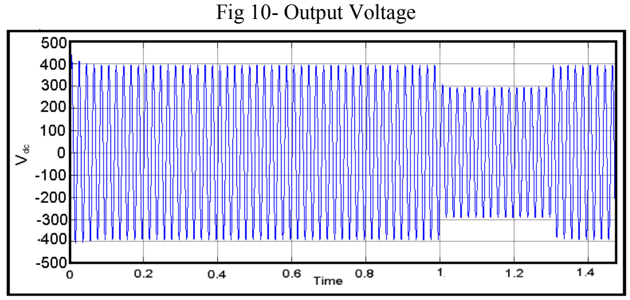

Fig 11- Harmonic waveform of Vdc

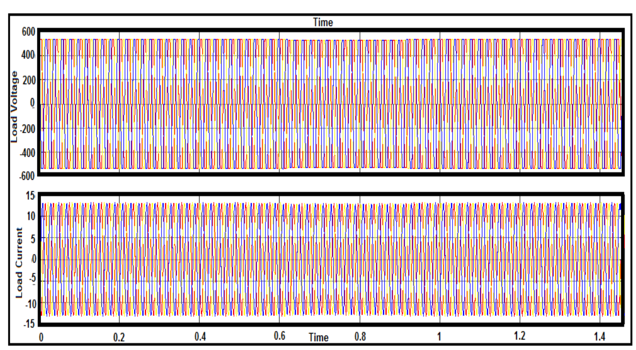

Fig 121- Load Voltage & Current Waveform

CONCLUSIONS

In this study, we have seen the architecture of a 8-switch power conditioner, that is alienated in 2 units, shunt-connected converter and series-connected converter. Its control system & its operation is simpler & good controllability is obtained.. It is very clear that the power quality achieved by using this system is recommendable compared to other lower switch systems & even a 9-switch system. The converter is associated in series with a passive LC filter pitched in seventh harmonic, creating good harmonic compensation performance system.

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