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RESEARCH ARTICLE

SHUNT HYBRID POWER FILTER AND THYRISTOR CONTROLLED REACTOR FOR POWER QUALITY

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ABSTRACT

A combined system of a thyristor controlled reactor (TCR) and a shunt hybrid Power filter (SHPF) is used for reactive power compensation and harmonic reduction. The SHPF is the combination of a small rating active power filter and a fifth harmonic tuned LC passive filter. Five level neutral points clamped (NPC) 180° mode converter is used in shunt active power filter to improve power quality without using higher passive elements which has a reduced switching stress and switching losses that improve the lifetime of converters. The TCR along with tuned passive filter is used for reactive power compensation, to improve the power factor. A nonlinear control is developed in proportional-integral controller for current tracking and voltage regulation, which is based on decoupled control strategy that considers the controlled system, may be divided into an inner fast current loop and an outer slow voltage loop. Thus, an exact linearization control was applied to the inner loop, and a nonlinear feedback control law is used for outer voltage loop. A simulation study of the implementation topology has been carried out using MATLAB.

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INTRODUCTION

Rising energy cost and a greater sensitivity to environmental impact of new transmission lines necessitated the search and application of new controllers to minimize losses and maximize the stable power transmission capacity of existing lines. In the first instance, these objectives were met by reactive power control on transmission lines. With the availability and applications of thyristors, new breed of thyristor-based reactive power controllers was realized which provided a very high speed of response. The rapid control feature added damping control to voltage and reactive power control applications. Flexible AC Transmission System (FACTS) technology is the application of a variety of new power electronic controllers for both active and reactive power on selected lines. FACTS controllers are becoming an integral component of modern power transmission systems. Power quality is any abnormal behavior on a power system arising in the form of voltage and current, which adversely affects the abnormal operation of electrical or electronic equipment. The major power quality issues are harmonic production and power factor reduction due to non-linear loads in the power system.

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(Fuchs and Masoum, 2008) Harmonics studies require a thorough understanding of the mechanics and operation of power system parameters and loads. The choice of measuring equipment is also important to ascertain a solution to these harmonic problems. Harmonic study involves, gathering a data resource and analyzing the data with power quality standards to evaluate network compliances with appropriate standards. There are many standards available, for example, the IEEE 519-1992 and IEC is the recommended practice and requirements for harmonic control in electrical power system. The best measure of power quality is the ability of electrical equipment to operate in a satisfactory manner, and the load should be designed for compatibility with the electrical system. The satisfactory operation of the electrical equipments for varying load conditions can be practically achieved through a software modeling called MATLAB/SIMULATION. The simulation results provide the necessary actions to be taken to improve the power quality of the system.

PROPOSED CIRCUITS DIAGRAM

The system consist of the thyristor controlled reactor, five level NPC inverter, PIC microcontroller, shunt active power filter, linear loads and nonlinear loads.

TCR is used to improve the power factor and five levels NPC inverter used to compress the harmonics. The PIC microcontroller is used to give the gate pulses to TCR and inverter circuits. Also, filter is used for smoothening the output waveform of inverter. The proposed circuits diagram is shown in Fig 1.

The controlling element is the thyristor controller; it has two back-to-back thyristors which conduct on alternate half-cycles of the supply frequency. If the thyristors are gated into conduction precisely at the peaks of the supply voltage then full conduction results in the reactor and the current as the same though the thyristor controller were short-circuited.

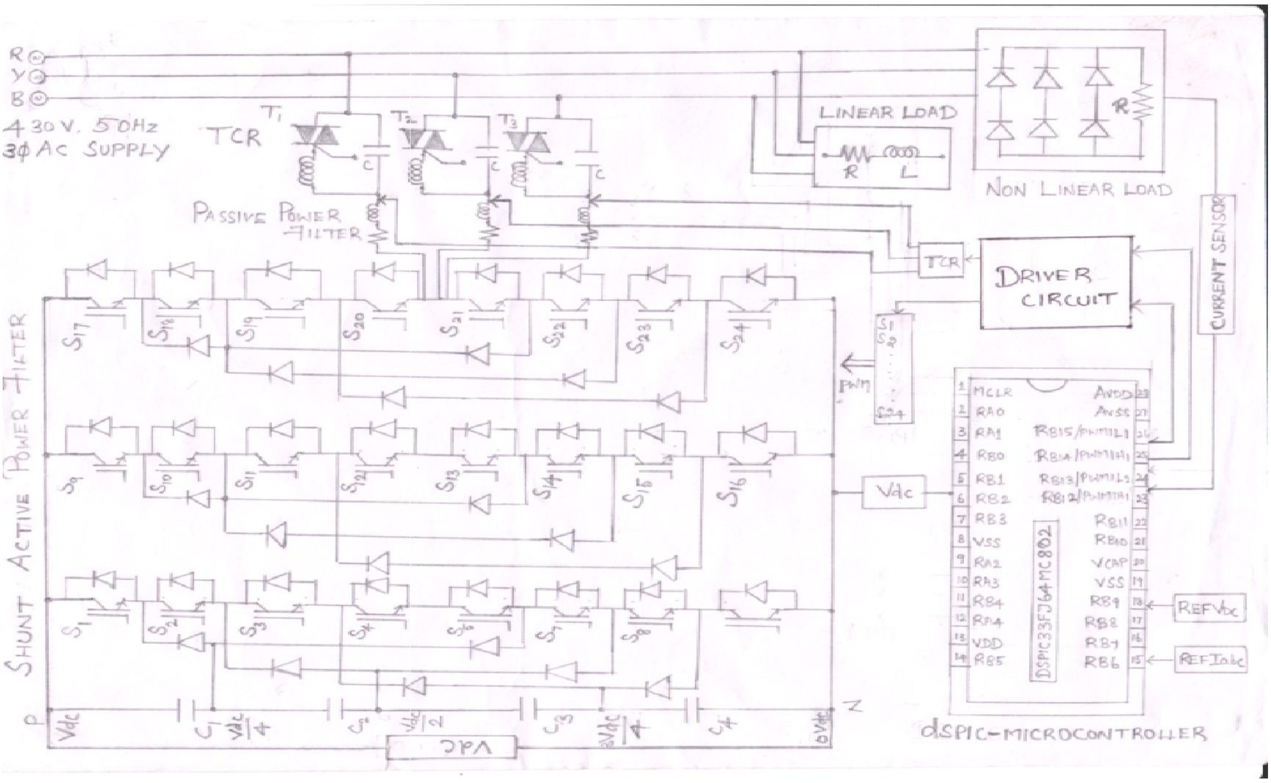


Figure 1. Proposed system circuit diagram

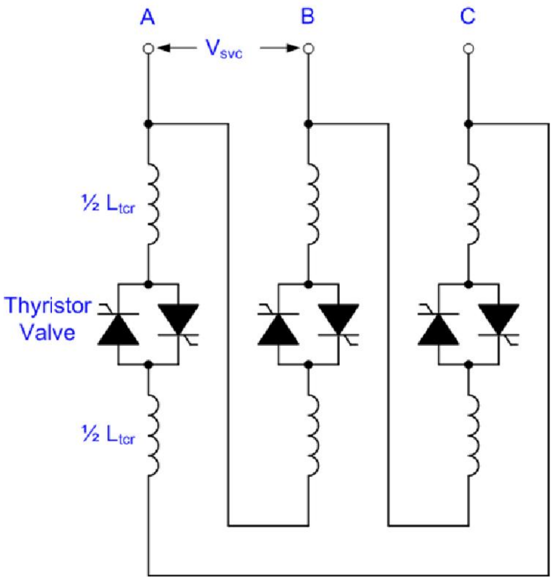


Figure 2. Thyristor controlled reactor

THYRISTOR CONTROLLED REACTOR

Thyristor-controlled reactor (TCR) is defined as: a shunt-connected thyristor controlled inductor whose effective reactance is varied in a continuous manner by partial conduction control of the thyristor valve, as shown in Fig 2.

The current is essentially reactive, lagging the voltage by nearly 90°. Full conduction is obtained with a gating angle of 90°. Partial conduction is obtained with gating angles between 90° and 180°. The effect of increasing the gating angle is to reduce the fundamental harmonic component of the current.

This is equivalent to an increase in the inductance of the reactor, reducing its reactive power as well as its current. So far as the fundamental component of current is concerned, the TCR is a controllable susceptance, and can therefore be applied as a static compensator.

A TCR consist of, reactor, which is usually air-cored and the thyristor valve up from the voltage handled by the thyristors to the transmission system voltage. A TCR operating with α > 90° generates substantial amounts of harmonic currents, particularly at 3rd, 5th and 7th harmonics. By connecting the TCR in delta, the harmonic currents of order 3n ("Triplen harmonics") flow only around the delta and do not escape into the connected AC system. However, the 5th and 7th harmonics (and to a lesser extent 11th, 13th, 17th etc.) must be filtered in order to prevent excessive voltage distortion on the AC network. This is usually accomplished by connecting Harmonic Filters in parallel with the TCR. The filters provide capacitive reactive power which partly offsets the inductive reactive power provided by the TCR.

FILTERS

POWER FILTERS

The different filters present in the literature are classified into three basic types. They are Active Filters, Passive Filters and Hybrid filter. Each type has its own sub classification. Fig. 3 shows the detailed classification of the filters.

Hybrid Power Filters

The active power filters are better solution for power quality improvement but they require high converter ratings. So the hybrid power filters are designed. (Asiminoaei *et al.,* 2008) The hybrid power filters are the combination of both active and passive power filters.
They have the advantage of both active and passive filters. There are different hybrid filters based on the circuit combination and arrangement.

They are

- Shunt Active Power Filter and Series Active Power Filter
- Shunt Active Power Filter and Shunt Passive Filter
- Active Power Filter in series with Shunt Passive Filter
- Series Active Power Filter with Shunt Passive Filter

Among the above filter combinations shunt active with passive type is best suited for power quality improvement in power system. The structure, modeling and control technique of hybrid active filter is discussed upcoming sections.

Shunt APF and Shunt Passive Filter

The voltage sourced inverter based Shunt APF. It is connected in shunt at the PCC. It injects the current which is equal and opposite of the harmonic current. It acts as a current source injecting harmonics and is suitable for any type of load.

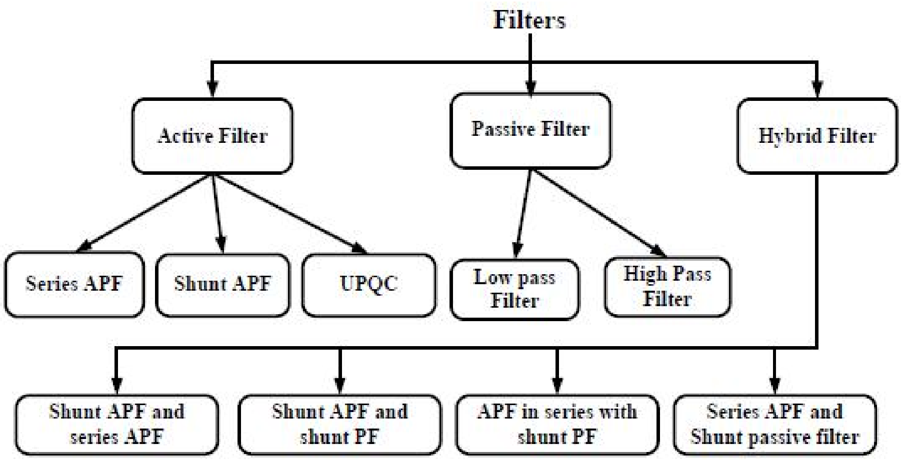


Figure 3. Types of filters

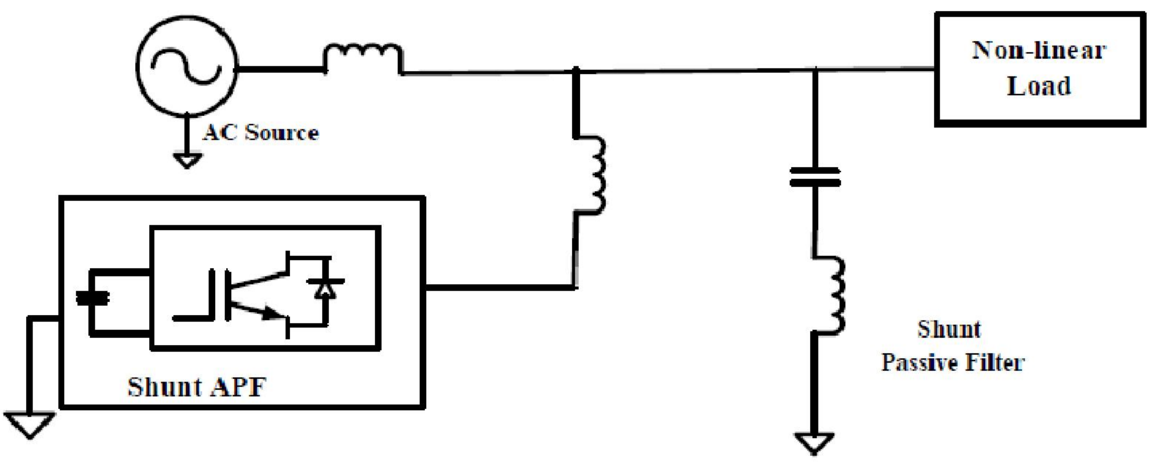


Figure 4. Hybrid power filters

It also helps in improving the load power factor. The power rating of the APF depend on the order of frequencies it is filtering out. Thus, an APF used for filtering out low order harmonics have low power rating with reduced size and cost. This logic is used in designing this filter combination. The shunt connected APF filters out the low order current harmonics while the shunt connected passive filter is designed to filter out the higher order harmonics. (Das, 2004) The circuit configuration of this filter topology is shown in Fig. 4.

FIVE LEVEL NPCINVERTER

In a three-phase structure of a five-level Neutral Point-Clamped inverter, the three phases of the inverter share a common DC bus. The five-level Neutral Point-Clamped inverter consists of four series-connected capacitors C1, C2, C3 and C4. The DC-link capacitors divide the DC bus voltage into five levels; namely 0, $V_{dc}/4$, $V_{dc}/2$, $3V_{dc}/4$ and V_{dc} these voltage levels appear at the output of each phase of the inverter by appropriate switching of the power semiconductor devices.

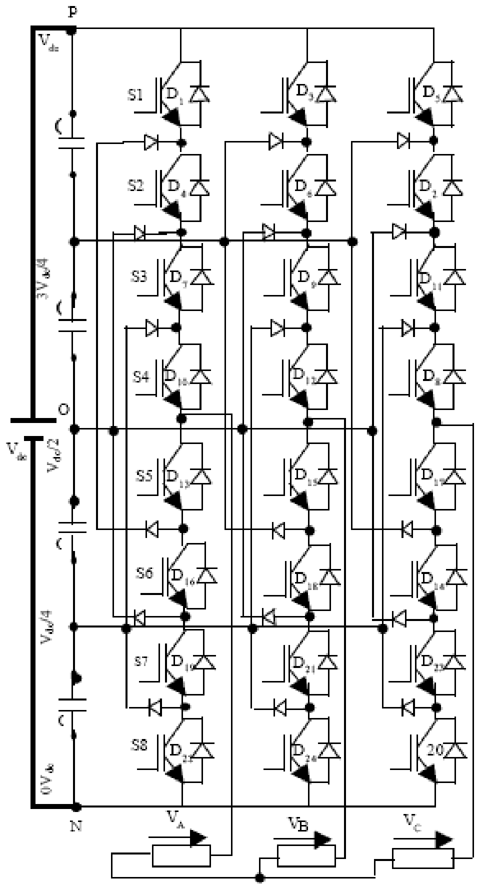


Figure 5. Five-level NPC inverter

Table 1. single phase NPC inverter switching table

Switching Table

Voltage levels	Switches															
	Sa1	Sa2	Sa3	Sa4	Sa1'	Sa2'	Sa3'	Sa4'	Sb1	Sb2	Sb3	Sb4	Sb1'	Sb2'	Sb3'	Sb4'
V1=0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
V2=Vdc/4	0	0	0	1	1	1	1	0	0	1	1	1	1	0	0	0
V3=2Vdc/4	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0
V4=3Vdc/4	0	1	1	1	1	0	0	0	0	0	0	1	1	1	1	0
V5=Vdc	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1

Modes of operation

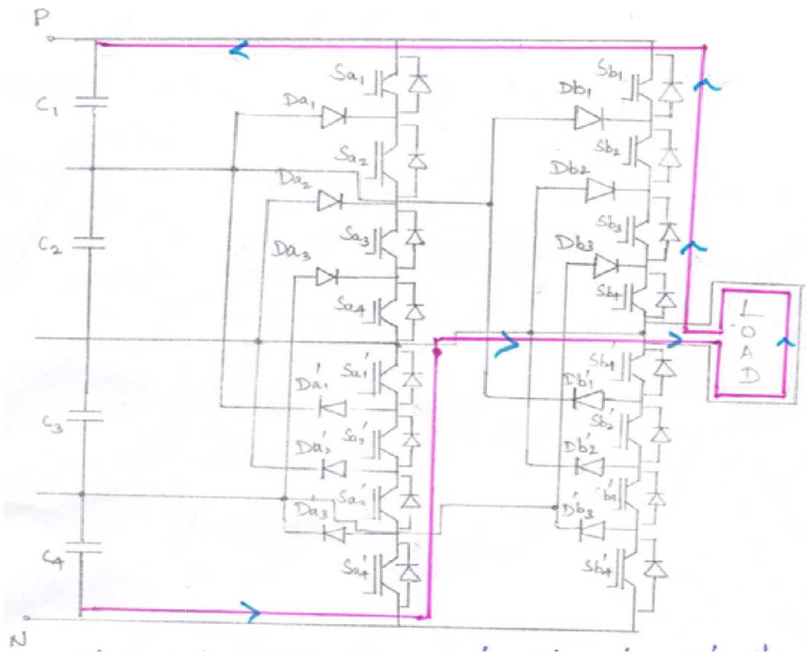
Mode 1: V_{dc}=0

Switches conducting: Sa1', Sa2' , Sa3', Sa4', Sb1, Sb2, Sb3, Sb4

The middle point of the four capacitors is denoted as 'n' which is the neutral point. There are four complementary switch pairs (S1, S1'), (S2, S2'), (S3, S3') and (S4, S4') and four clamping diodes (D1, D2, D3 and D4) per phase present in this inverter. The upper four switches are the main switching devices (S1, S2, S3 and S4) that operate for pulse width modulation while the lower four switches are the complementary switching devices (S1', S2', S3' and S4') that clamp the output terminal potential to the neutral point potential along with the help of the four clamping diodes The inverter act in 180° mode of voltage source inverter (VSI). NPC inverter is shown Fig.5,6,7,8,9,10

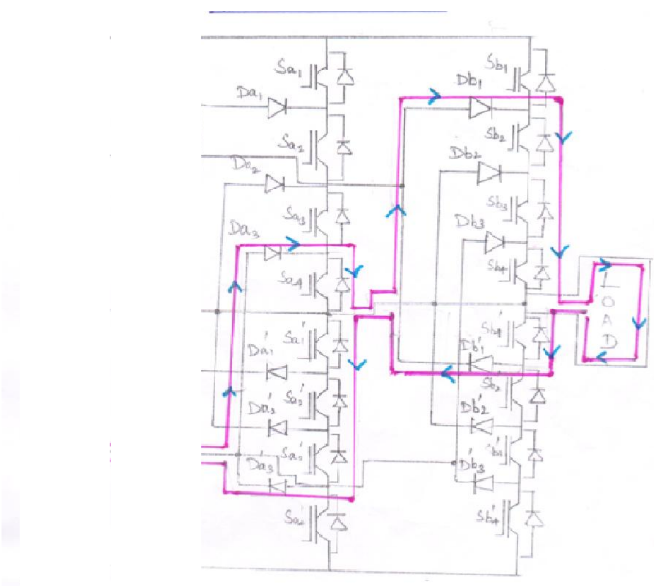
CONTROL STRATEGIES/ALGORITHMS

In any active power filter system, control algorithms has major role in deciding the performance of harmonic compensation. The gate pulses provided are using the control algorithms to the voltage source inverter used in filtering system. It makes a closed loop control on the harmonic current present in the line and compares with ac sinusoidal source to get the error. This error is passed through some controllers and control algorithms to generate pulses for VSI. The reliability and performance of any active power filtering largely depend on control algorithms adopted, there are number of algorithms proposed in the last



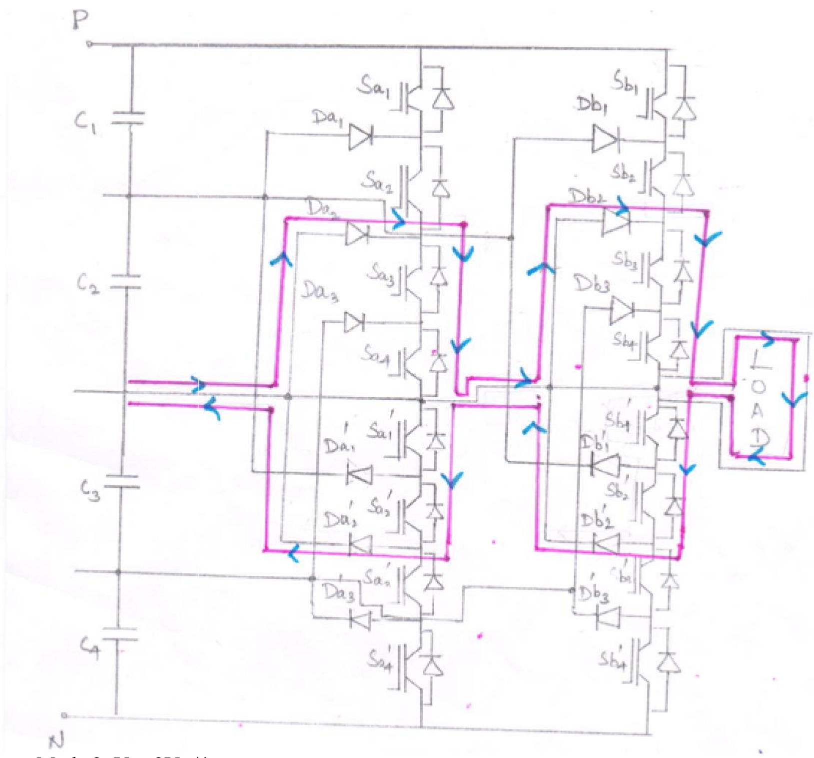
Mode 2: $V_{dc}=V_{dc}/4$
Switches conducting: Sa4, Sa1', Sa2', Sa3', Sb2, Sb3, Sb4, Sb1'.
Clamping diodes: Da3,Da3',Db1,Db1'.

Figure 6. level 0 Vdc=0



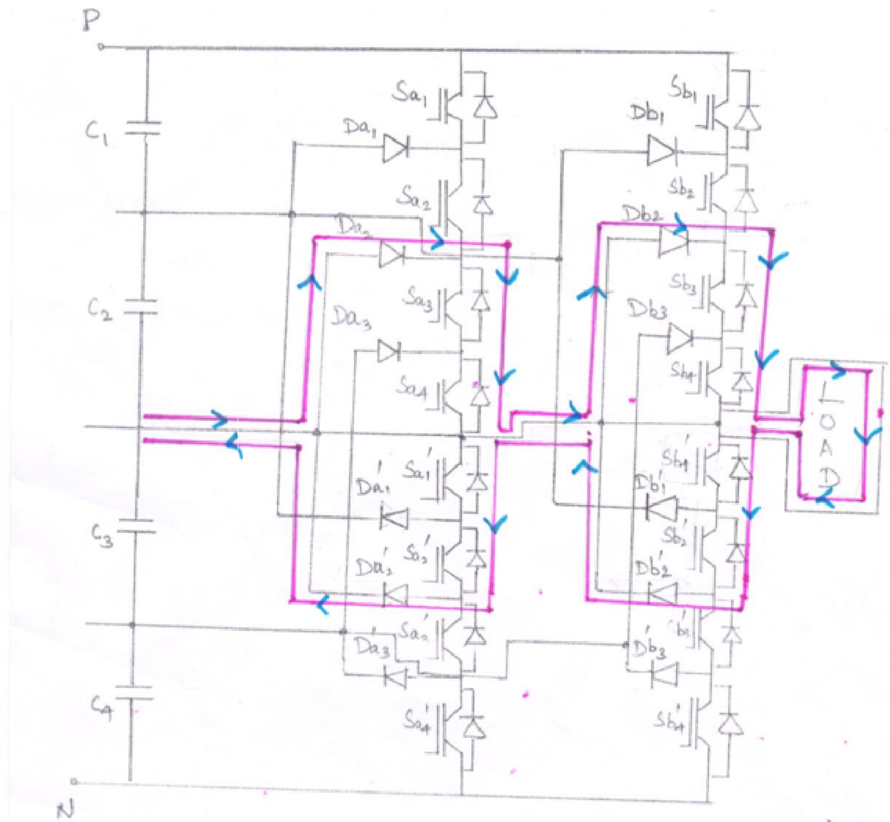
Mode 3: $V_{dc}=2V_{dc}/4$
Switches conducting: Sa3,Sa4,Sa1',Sa2',Sb3,Sb4,Sb1',Sb2'.
Clamping Diodes: Da2,Da2',Db2,Db2'.

Figure 7. level 1 Vdc=Vdc/4



Mode 3: $V_{dc}=3V_{dc}/4$
Switches conducting: Sa3,Sa4,Sa1',Sa2',Sb3,Sb4,Sb1',Sb2'.
Clamping Diodes: Da2,Da2',Db2,Db2'.

Figure 8. level 2 Vdc=2Vdc/4



Mode 5: $V_{dc}=V_{dc}$
Switches conducting: Sa1,Sa2,Sa3,Sa4,Sb1',Sb2',Sb3',Sb4'.
Clamping Diodes: Da1,Da2,Da3,Db1',Db2',Db3'.

Figure 9. level 3 Vdc=3Vdc/4

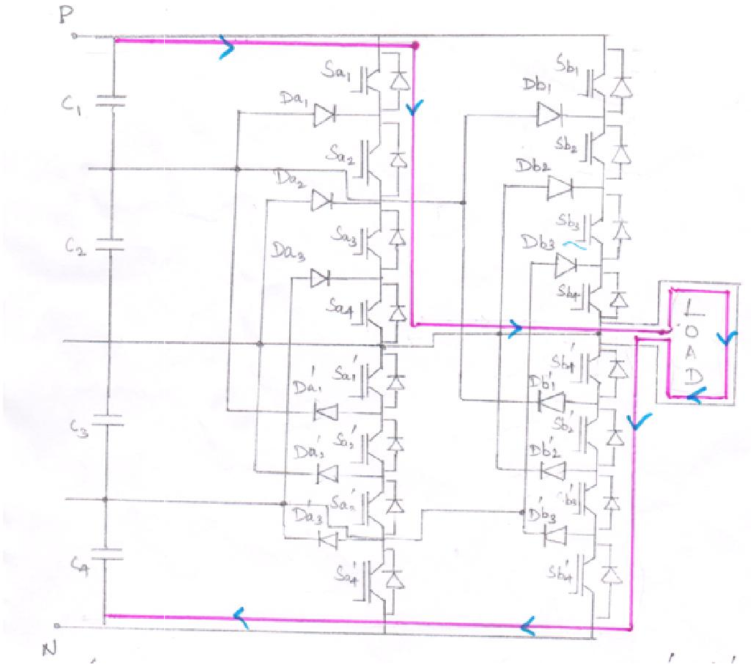


Figure 10. Level 3 Vdc=Vdc

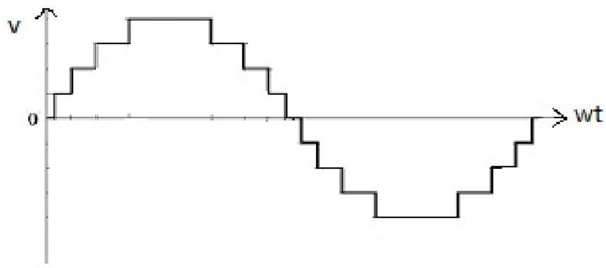


Figure 11. Waveform of five level npc inverter

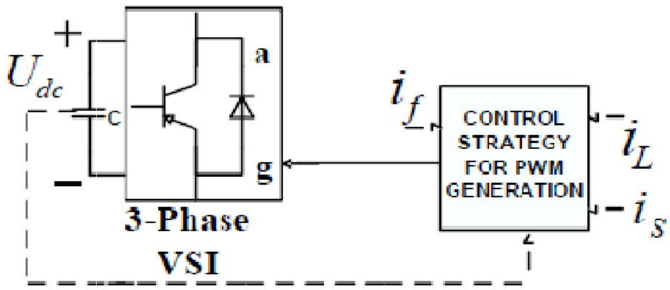


Figure 12. Control strategy of SHPF

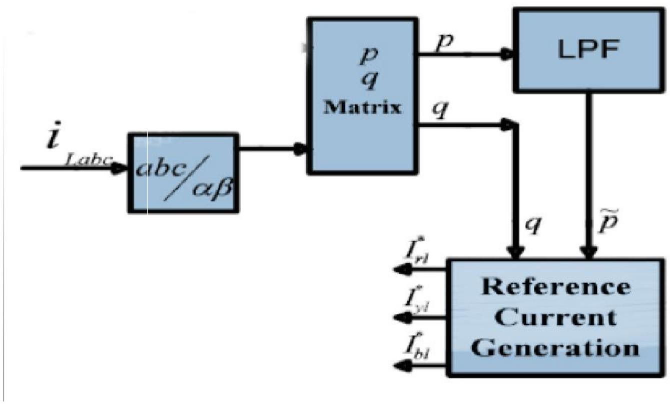


Figure 13. p-q control theory

decade some of which work good under balanced and unbalanced conditions also. The performance of compensation of harmonics of source current largely depend on the algorithm adopted since the control methods are responsible for generating the reference currents which used to trigger the Voltage Source Inverters (VSI). The control strategy of SHPF is shown in Fig. 12

- The APF needs an accurate control algorithm that provides robust performance under source and load unbalances.
- Better control strategy leads to better dynamic response of the system.

Instantaneous reactive power theory

This theory was developed by Akagi and co. The use of this theory is for transforming a three phase three wire system to two phase system. The original theory was named *p-q* transformation the control strategy that was found from the *p-q* theory was effective in the target proposed; sinusoidal source currents after compensation, with the same characteristics as the supply voltages. This control algorithm gives a basic way to find the reference currents for the Shunt APF system. The theory is based on the park transformation it transfers the three - phase axis mains voltages and currents to α β axis. The component represents the fluctuating part of real power and it does not involve any useful energy transfer from source to load so it must be compensated. Similarly, the reactive power involved with the load must be compensated by the shunt APF. Hence the reference signal of compensation current in the *dq* axes can be given as in (3). And using the inverse park transformation we get the reference currents back to three-phase system which is shown in Fig. 13.

SIMULATION MODEL OF PROPOSED SYSTEM

Matlab/simulink model of shunt hybrid power filter with thyristor control reactor for power quality is shown in below. It consists of TCR, five level NPC inverter, shunt hybrid power filter, DSPIC microcontroller, linear and nonlinear Load (Fujita and Akagi, 1991)

The above waveform is the FTT analysis of before and after compensation of harmonic reduction. The Total Harmonic Distortion (THD) value of before compensation is 8.22% and the after compensation of THD value is 2.87%.

Conclusion

The MATLAB/SIMULINK result of the proposed system at different operating conditions is obtained. The system is simulated for harmonics reduction and reactive power compensation. By using FTT analysis, the THD value of harmonics is compared for before and after compensation. From the results it is inferred that the Shunt Active Power Filter is very helpful in improving the power quality of the system by filtering out the harmonics. The proposed system simulation result have achieved the THD value as 2.87% and the power factor of the system is improved to a value of 0.9999% through reduced switching stress, losses and improved efficiency.

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