# By using Indirect Current Control Technique of Shunt Active Power Filter for Harmonic Mitigation using MATLAB and Simulation

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*Abstract*— Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy." This definition embraces two things that we demand from an electrical device: performance and life expectancy. Any power-related problem that compromises either attribute is a power quality concern Harmonic distortion problem has existed in the power system for a long time. It causes a wave of the line current and voltage in the power system to be distorted. Presently, increased use of non – linear loads in industry and the creation of modern equipment, especially electronic equipment have produced harmonic distortion. The primary objective of this paper is to reduce the harmonics with the help of a indirect control shunt active filter for both the load Non linear and linear load. PI and Hysteresis controller are used in this paper work. Single phase and three phase shunt active power filter comparison is also discussed.

***Key words:*** Hysteresis controller, PI controller

## I. Introduction

The word "Power Quality" has become a very important aspect of power delivering. The power quality has became an issue recently, does not mean that it was not important in the past. Utilities all over the world have for decades worked on the improvement of what is now known as power quality and it can be explained in number of ways. Tripping of equipment due to disturbances in the supply voltage is often described by costumers as "Bad Power Quality". The main issue is the non sinusoidal current of rectifier and inverters. The input current not only contains power frequency component (50HZ) but also, so called harmonics component with frequencies equal to a multiple of power frequency. The later cause a large part of harmonic voltage distortion. Each individual device does not generate much harmonic current but all of them together cause a serious distortion of the supply voltage.

### A. Solution of Power Quality Compliments

Earthling Practices, Grid Adequacy Planning, Energy Storage Devices, Transient Voltage Surge Suppressers (TVSS), Constant Voltage Transformers, Noise Filters, Isolation Transformers and Harmonic Filters etc.

### B. Harmonic Filters

Harmonic filters are used to reduce undesirable harmonics. They can be divided in two groups: passive filters and active filters.

Passive filters consist in a low impedance path to the frequencies of the harmonics to be attenuated using passive component (Inductors, capacitors and resistors). Several passive filters connected in parallel may be necessary to eliminate several harmonic components. If the system varies (change of harmonic components), passive filters may become ineffective and cause resonance. Active filters analyze the current consumed by the load and create a current that cancel the harmonic current generated by the loads. Active filters were expensive in the past, but they are now becoming cost effective compensating for unknown or changing harmonics.

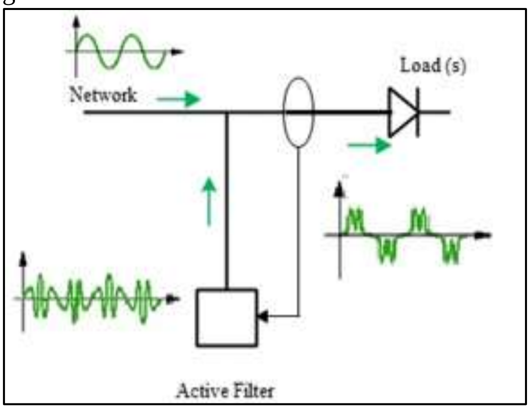



Fig. 1: Active filter

## II. FUNDAMENTAL OF HARMONICS

### A. Harmonics

Harmonics are measured in integer multiples of the fundamental supply frequency. It is periodic sinusoidal distortions of the supply voltage or load current caused by non – linear loads

### B. Harmonic Distortion

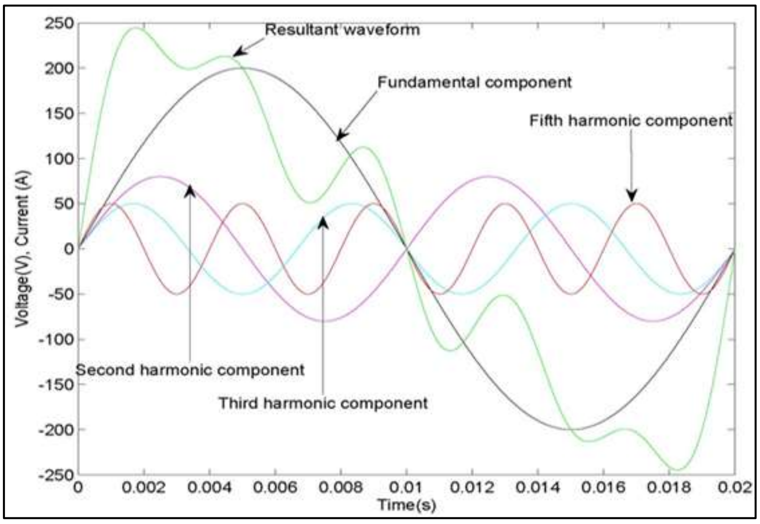



Fig. 2: Components of harmonics in power system

Harmonics can be defined as the undesirable components of a distorted periodic waveform whose frequencies are the integer multiples of the fundamental frequency.

A sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency.

Non-sinusoidal periodic waves contain fundamental and higher order frequency components. These higher order frequency components are called harmonics.

Two compensation techniques are

1) Shunt passive filter
2) Series passive filter

The series filter is characterized as a parallel resonant blocking type, which has high impedance at its tuned frequency, e.g. smoothening reactor in power systems. The shunt filter is characterized as a series resonant and traps type, which has a low impedance path at tuned frequency.

Shunt passive filter consist of tuned LC circuits that are used to suppress harmonics in power system, shunt passive filters exhibit lower impedance at the tuned harmonic frequency than the source impedance. This diverts the harmonic current to the tuned filter thereby, reducing the harmonic currents flowing into the source.

## III. ACTIVE FILTER RECOMMENDED STRATEGY

Fig. 3 shows the basic APF block diagram including non-linear load on three-phase supply conditions. The main objective of the APF installation by individual consumers is to compensate current harmonics or current imbalance of their own harmonic-producing loads. Moreover, the purpose of the APF installation by the utilities is to compensate for voltage imbalance or provide harmonic damping factor to the power distribution systems.

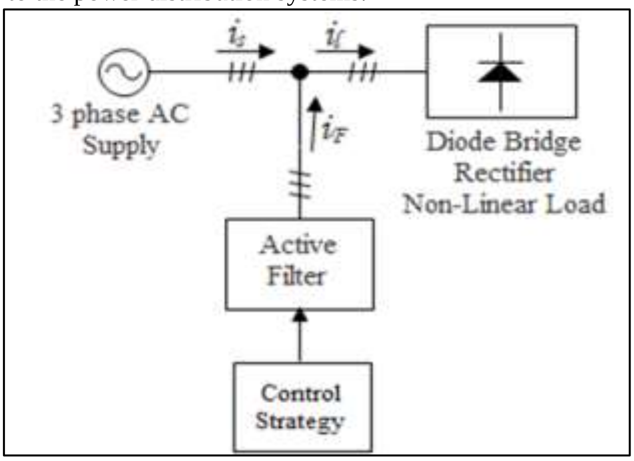



Fig. 3: Block diagram of APF

## *A. Control Scheme*

Control scheme presents the basic building blocks of the conventional parallel AF. It consists of a standard 3-phase voltage source inverter bridge with a dc bus capacitor to provide an effective current control. To obtain fast response of the AF a hysteresis based carrier less PWM current control is employed. The non-linear load is a dc resistive load supplied by 3-phase uncontrolled bridge rectifier with an input impedance and dc capacitor on the output. The uncontrolled bridge rectifier draws non sinusoidal pulsating currents from ac source due to capacitive loading. It also draws reactive power from the mains depending upon the load magnitude and its parameters. The basic function of the proposed parallel AF is to eliminate harmonics and meet the reactive power requirements of the load locally so that the ac supply feeds only the sinusoidal balanced unity power factor currents. By sensing the load current, dc bus voltage, and source voltage the desired AF currents are estimated. To force the desired currents into the AF phases the hysteresis current controller generates the switching signals to AF devices. With this control feature, the AF meets harmonic and reactive current requirements of the load. It enhances the system efficiency as the source does not process harmonic and reactive power as the AF connected in shunt with the load.

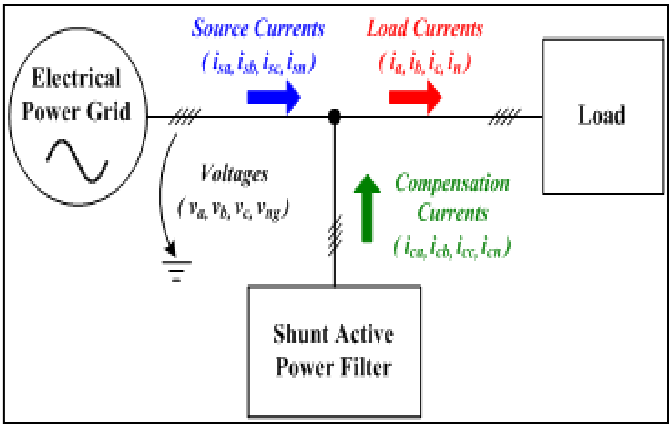



Fig. 1**:** Basic Building Block of the Active Filter

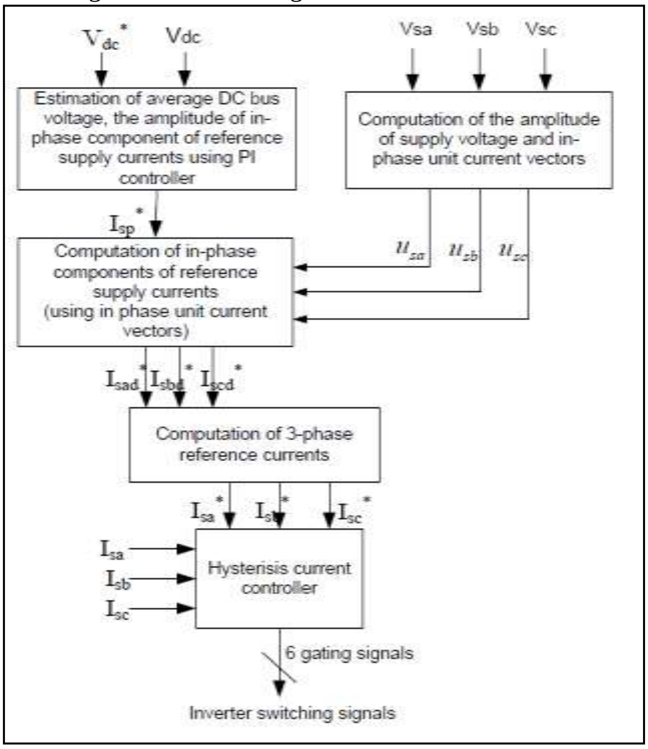



Fig. 2**:** Scheme of the AF

Comparison of Average value of DC bus voltage (Vdc) and reference value of dc bus voltage (Vdc*) of the AF results in a voltage error, which is fed to a PI controller as shown in figure.

$$V_{dcerror} = V_{dc}^* - V_{dca} \quad (1)$$

## *B. Peak Source Current Estimation*

The instantaneous power $P_L$ is,

$$P_L = V_{sa}\, i_{La} + V_{sb}\, i_{Lb} + V_{sc}\, i_{Lc}$$

Here, $i_{La}$, $i_{Lb}$ and $i_{Lc}$ are three phase sensed load currents and $V_{sa}$, $V_{sb}$ and $V_{sc}$ are the sensed 3-phase source voltages and under ideal conditions these can be expressed as

$$V_{sa} = V_{sp} \sin\omega t \quad (2)$$

$$V_{sb} = V_{sp} \sin(\omega t - 2\pi/3) \quad (3)$$

$V_{sc} = V_{sp} \sin(\omega t + 2\pi/3)$

In Eq. (2), Vsp is the peak of source voltage and ω is the frequency of the ac mains in rad/sec.

By sampling the actual dc bus voltage the average ($V_{dca}$) is computed over the one sixth period of supply frequency (Tx). The energy difference corresponding to $V_{dc}^*$, and $V_{dca}$ over the Tx, is:

$$\Delta e_{dc} = e^*_{dc} - e_{dc} = C_{dc}[(V_{dc}^*)^2 - V^2_{dca}]/2 \quad (4)$$

*C. Source Reference Currents Generation*

Now, Three-phase in-phase components of the reference supply currents are computed using their amplitude and in phase unit current vectors derived in-phase with the supply Voltages, and are given by

$i_{sa}^* = I^*_{sp}.\, u_{sa}$

$$i_{sb}^* = I^*_{sp}.\, u_{sb} \quad (5)$$

$i_{sc}^* = I^*_{sp}.\, u_{sa}$

Where usa, usb and usc are in – phase unit current vectors and are derived as -

$u_{sa} = V_{sa}/V_{sp}$

$$u_{sb} = V_{sb}/V_{sp} \quad (6)$$

$u_{sc} = V_{sc}/V_{sp}$

Where Vsp is the amplitude of supply voltage and it is computed as

$$V_{sp} = \left\{{}^{2}/_{3}\,(v_{sa}^2 + v_{sb}^2 + v_{sc}^2)\right\}^{1/2} \quad (7)$$

Hence from the above procedure, the three phase reference supply currents are computed.

Now the three-phase reference supply currents and sensed supply currents are given as inputs to hysteresis current controller which generates gating signals for IGBT's of the AF.

*D. Reference AF Currents Generation*

The 3-phase AF reference currents are estimated using the reference source currents in Eq. (8) and the sensed load currents as:

$I^*_{ca} = i^*_{sa} - i^*_{La}$

$$I^*_{cb} = i^*_{sb} - i^*_{Lb} \quad (8)$$

$I^*_{cc} = i^*_{sc} - i^*_{Lc}$

*E. Hysteresis Based Current Controller*

The current controller decides the switching pattern of the AF devices. The switching logic is formulated as follows:

If ica < (i*ca – hb) upper switch is OFF and lower switch is ON for leg 'a' (SA = 1).

If ica > (i*ca + hb) upper switch is ON and lower switch is OFF for leg 'a' (SA = 1).

The switching functions SB and SC for phase's b and c are determined similarly, using the corresponding reference and measured currents and the hysteresis band hb.

The AF currents ica, icb and icc are regulated to be in good agreement with the reference values i*ca, i*cb and i*cc.

*F. Active Filter (AF)*

Three- phase ac source through the source inductances is the input to the AF (3-phase VSI Bridge) and dc bus with a capacitor ($C_{dc}$) is its output. The AF operating in the current

Controlled mode is modeled by the following differential equations:

$$Pi_{ca} = -(R_c/L_c)\, i_{ca} + (V_{sa} - V_{ca})/Lc \quad (9)$$

$$Pi_{cb} = -(R_c/L_c)\, i_{cb} + (V_{sb} - V_{cb})/Lc \quad (10)$$

$$Pi_{cc} = -(R_c/L_c)\, i_{cc} + (V_{sc} - V_{cc})/Lc \quad (11)$$

$$pV_{dc} = (i_{ca}SA + i_{cb}SB + i_{cc}SC)/Cdc \quad (12)$$

Where p is the differential operator (d/dt). SA, SB and SC are the switching functions decided by the switching status of the AF devices. $V_{ca}$, $V_{cb}$ and $V_{cc}$ are the 3-phase PWM voltages reflected on ac input side of the AF expressed in terms of the instantaneous dc bus voltage ($V_{dc}$) and switching functions as:

Vca = (Vdc/3) (2SA – SB – SC)

$$Vcb = (Vdc/3)\,(-SA + 2SB - SC) \quad (13)$$

Vcc = (Vdc/3) (- SA +SB+2SC)

*G. Non Linear Load*

A 3-phase uncontrolled diode bridge rectifier with input impedance and capacitive-resistive loading is taken as a non-linear load (Fig.1). It has two operating modes based on the diode conduction state.

When the diodes are conducting, the ac source (line-line voltage) is connected to the load and the basic equations are:

$2R_s\, i_d + 2Lspi_d + V_L = V_s$

This may be modified as:

$$Pi_d=(V_s-V_L-2R_si_d)/(2L_s) \qquad (14)$$

The capacitor charging/discharging equation is:

$$pV_L=(i_d-i_R)/C_L \qquad (15)$$

where Rs and Ls are the resistance and inductance of the ac source. CL is the load capacitance on the dc side and VL is the instantaneous voltage across it. "id" is the current flowing from ac source through a diode pair to charge the capacitor CL and iR is the resistive load current (VL/RL).

"Vs" is the ac source line voltage segment (Vsab, Vsba,Vsbc, Vscb, Vsca or Vsac) depending on which diode pair is conducting. Similarly the load currents in all the 3-phases of the ac source (iLa, iLb and iLc) are obtained using the magnitude of id and sign corresponding to conducting pairs of diodes. When none of the pairs of diodes is conducting, id and its derivative will be zero. However, charged capacitor CL will be discharged through load resistor RL and equation (15) will be modified accordingly.

The set of first order differential equations (9), (10), (11), (12), (14) and (15) along with other expressions define the dynamic model of the AF system. These equations are solved using fourth order Runga - Kutta method I FORTRAN to analyze the dynamic and steady state performance of the AF system. A standard FFT package is used to compute the harmonic spectrum and THD of the ac load and source currents.

### *H. PI Controller*

A PI controller calculates an "error" value as the difference between a measured process variable and a desired set point. It is a control loop feedback mechanism (controller) widely used in industrial control systems (Programmable Logic Controllers, SCADA systems, Remote Terminal Units etc). Simulation of PI controller is shown below:

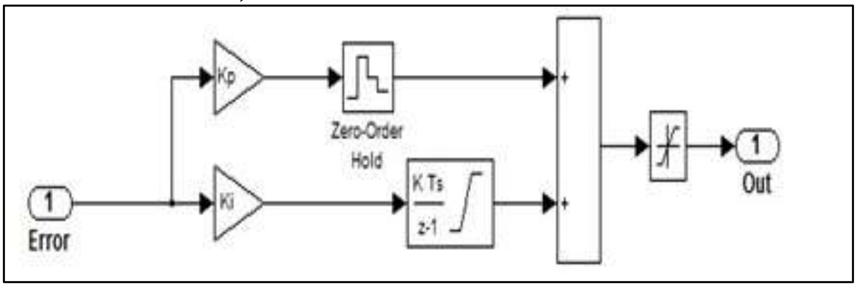



Fig. 5: circuit of PI Controller

### *I. Hysteresis Controller*

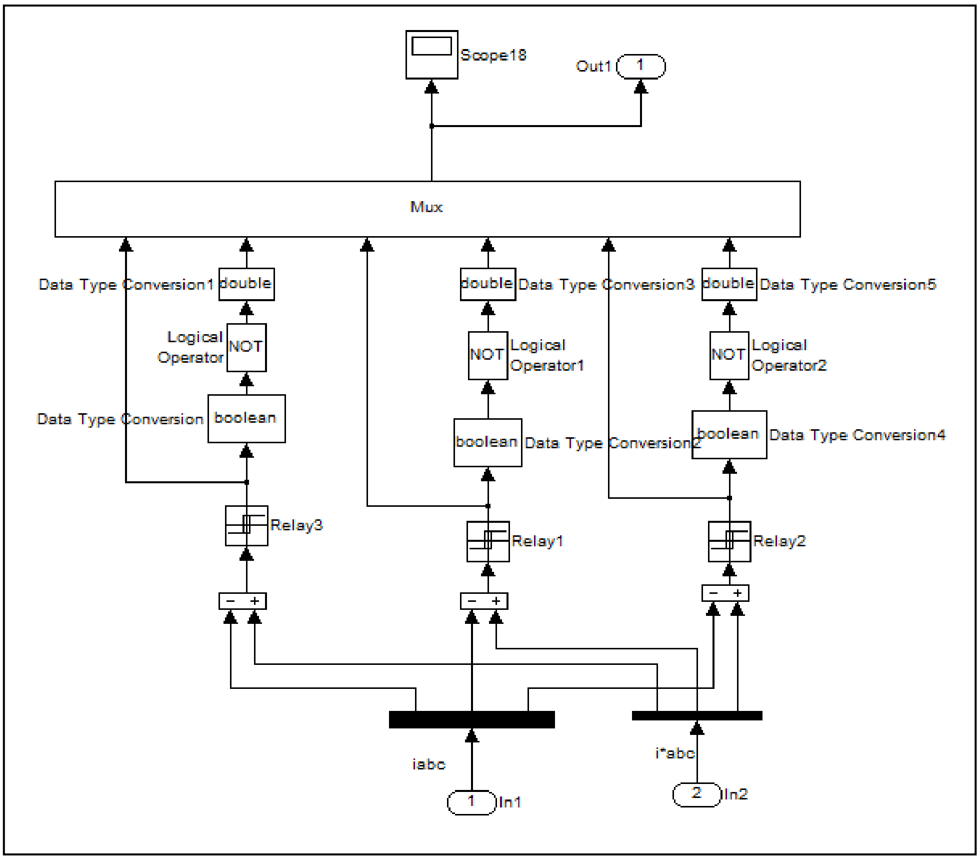



Fig. 3: Circuit of Hysteresis Controller

In order to estimate the reference current command, the source voltages and load currents of two phases are measured and their harmonic components are computed.Using fundamental load current(I1), fundamental volatge(V1 ), harmonic components of voltage(V3,V5 ………..) and their respective angles(θ1θ2θ3θ4θ5……), reference currents are obtained. Using a negative adding circuit the third reference current can be obtained. to obtain the loss component and added with the fundamental component of load current ,DC bus capacitor volatge is regulated. To obtain the switching signals, estimated refrence currents and the actual mians currents are then processed in hysteresis controller

## IV. RESULT AND WAVEFORM

### *A. Simulation circuit of single phase shunt active power filter*

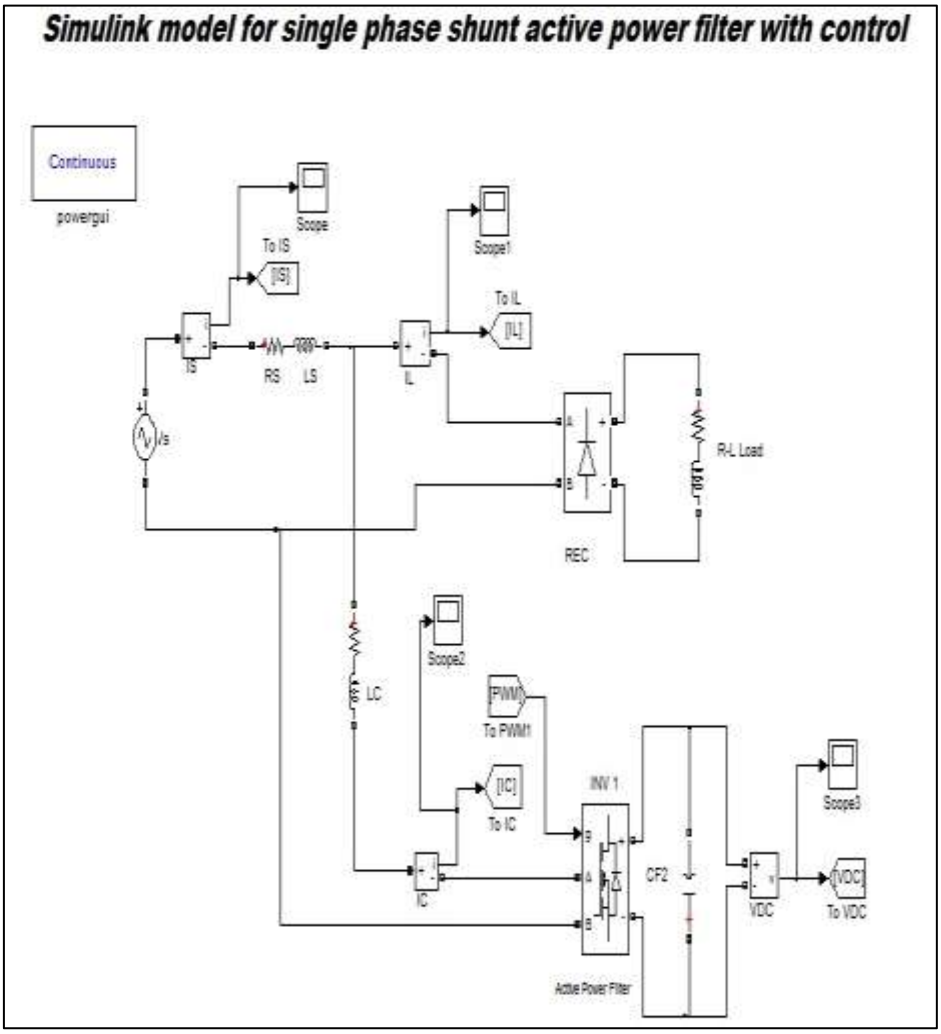



Fig. 4**:** Simulation circuit of single phase shunt active power filter

### *B. System Parameter Values for Single Phase Shunt Active Power Filter*

| S. No. | System parameters | Values |
|---|---|---|
| 1. | Supply peak voltage | 440V |
| 2. | Source inductance & resistance | Ls = 1mH, Rs = 3Ω |
| 3. | Coupling parameters | Lc = 2mH, Rc = 1.5 Ω |
| 4. | DC capacitor voltage | 500V |
| 5. | Hysteresis band (HB) | 1 |
| 6. | Proportional constant (kp) | 0.1 |
| 7. | Non linear Load Details | Diode bridge rectifier with R =30 Ω , L = 30mH |
| 8. | Frequency | 50Hz |
| 9. | DC link capacitor (SAPF) | 1500µF |
| 10. | Simulation time | 0.2s |

Table 1:

### C. Single Phase Shunt Active Power Filter

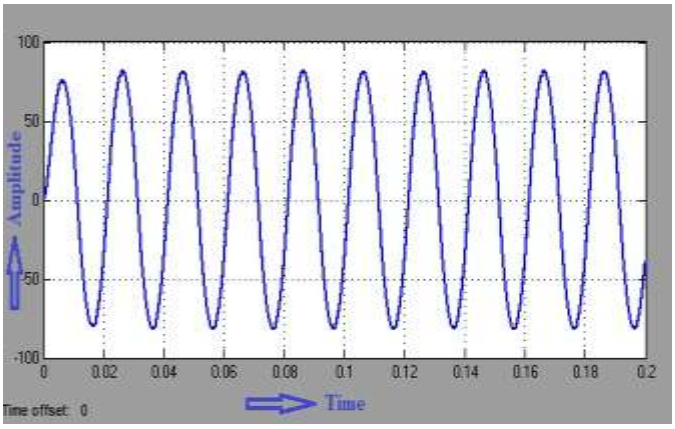



Fig. 5**:** Voltage Source of Single Phase Shunt Active Power Filter

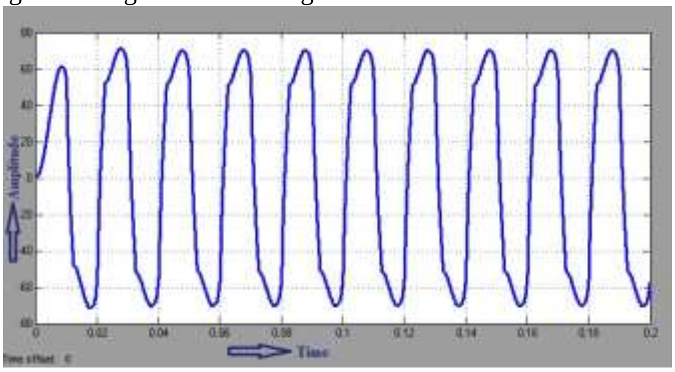



Fig. 6**:** Load Current of Single Phase Shunt Active Power Filter

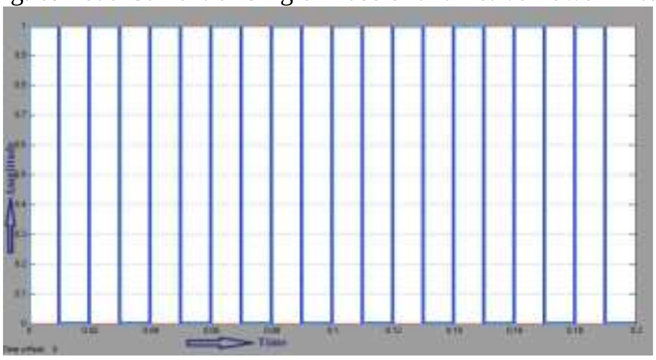


Fig. 7**:** Hysteresis Controller of Single Phase Shunt Active

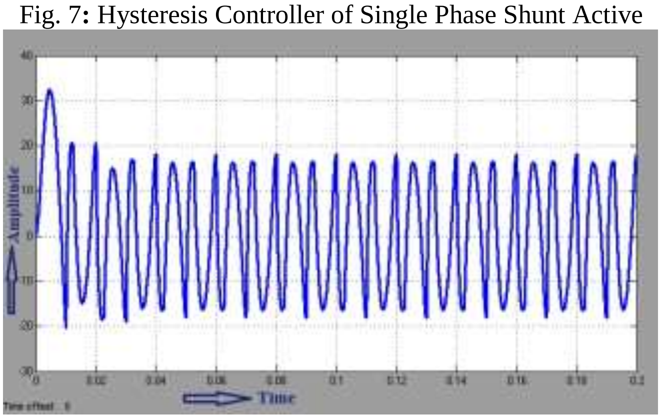



Fig. 8**:** Compensating Current of Single Phase Shunt Active Power Filter

### D. Simulation for Three Phase Shunt Active Power Filter

| S. No. | System parameters | Values |
|---|---|---|
| 1. | Supply peak voltage | 440V |
| 2. | Frequency | 50Hz |
| 3. | Source inductance & resistance | Ls = 0.5mH, Rs = 0.1Ω |
| 4. | Coupling parameters | Lc = 3.25mH, Rc = 0.4 Ω |

| | | |
|---|---|---|
| 5. | DC link capacitor (SAPF) | 1500µF |
| 6. | DC capacitor voltage | 700V |
| 7. | Hysteresis band (HB) | 0.5 |
| 8. | Proportional constant (kp) | 0.1 |
| 9. | Simulation time | 0.2s |
| 10. | Non linear Load Details | Diode bridge rectifier with R = 30, L = 30mH |

Table 2: System Parameter Values for Three Phase Active Power Filter

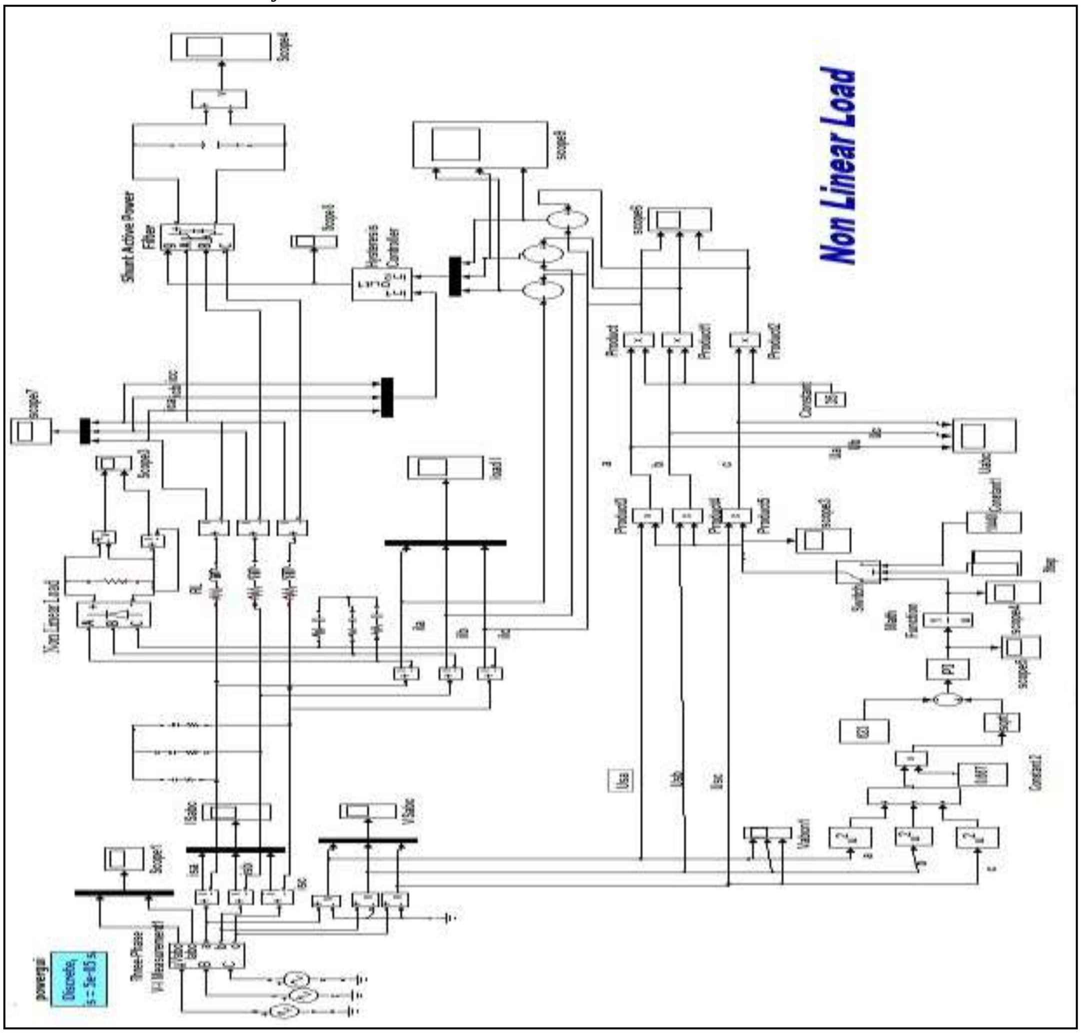
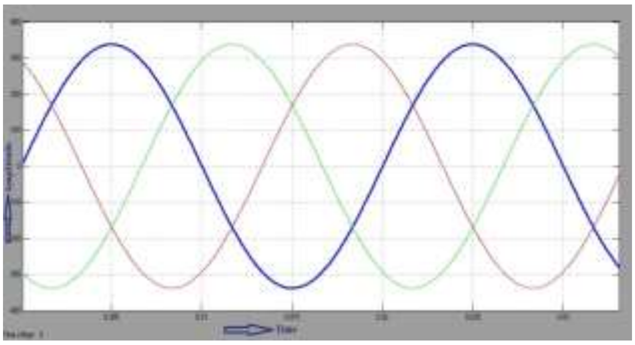



Fig. 9**:** Simulation circuit of three phase shunt active power filter for Non Linear Load

*E. Simulated waveforms of Three Phase Shunt Active Power Filter*

*1) Non Linear Load*



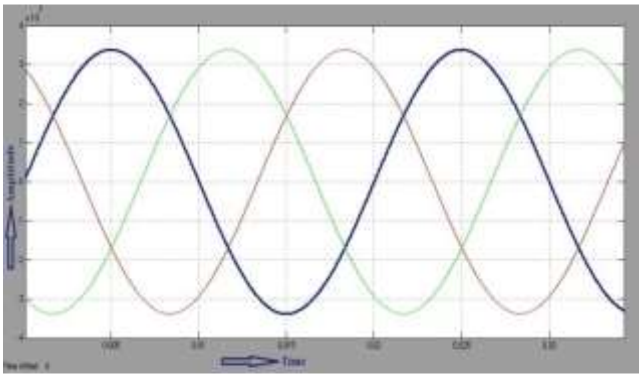


Fig. 10: Voltage & Current Source for Non Linear Load

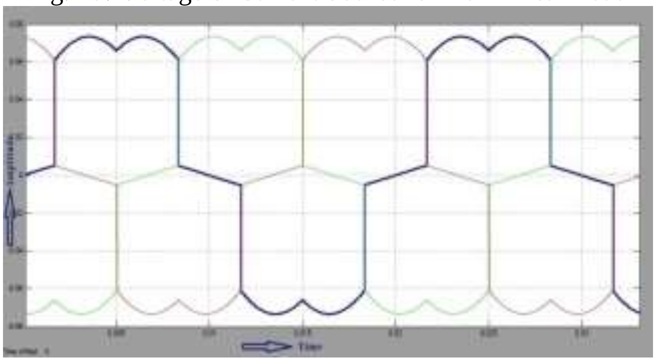


Fig. 11: Load Current for Non Linear Load

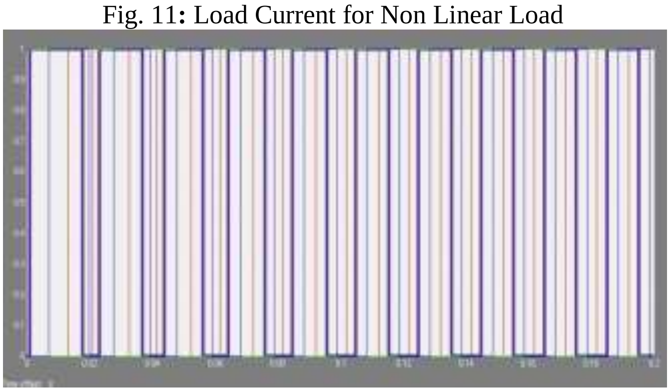


Fig. 12: Hysteresis Controller for Non Linear Load

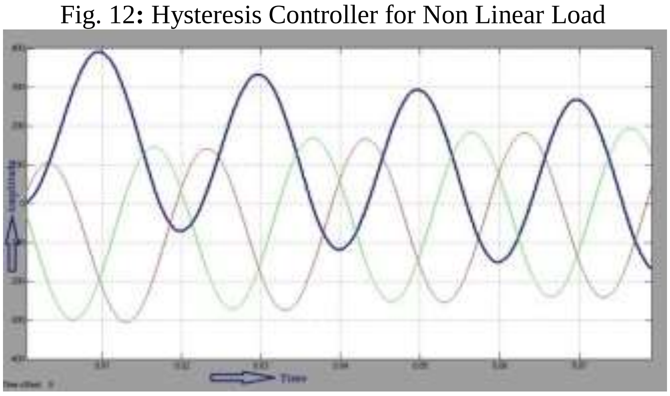


Fig. 13: Compensating current for Non Linear Load

### *F. Simulink model for Three Phase Shunt Active Power Filter with Linear Load*

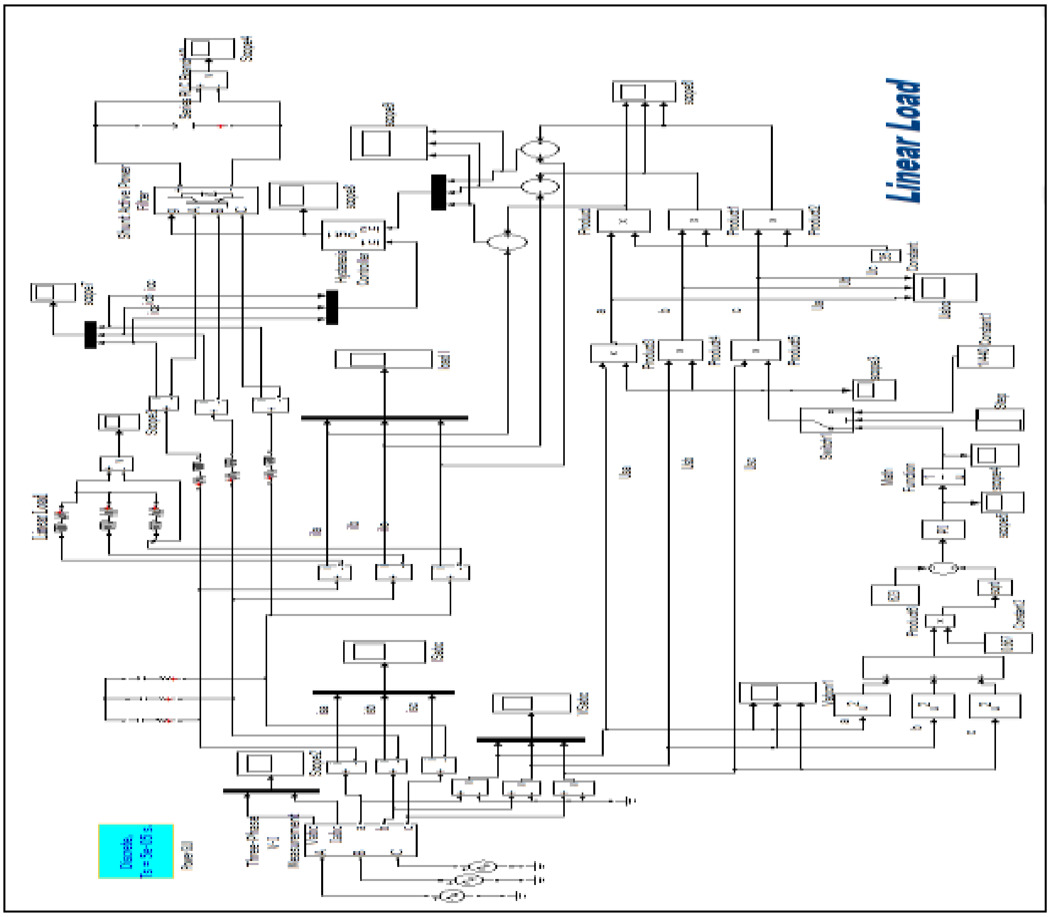
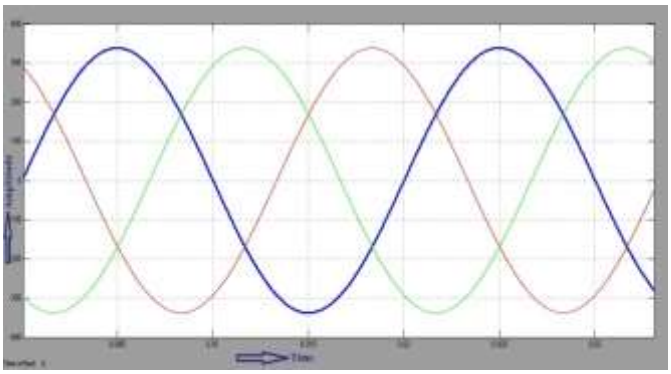


Fig. 17:

| S. No. | System parameters | Values |
|---|---|---|
| 1. | Supply peak voltage | 440V |
| 2. | Frequency | 50Hz |
| 3. | Source inductance & Source resistance | Ls = 0.5mH, Rs = 0.1Ω |
| 4. | Coupling parameters | Lc = 3.25mH, Rc = 0.4 Ω |
| 5. | DC link capacitor (SAPF) | 1500µF |
| 6. | DC capacitor voltage | 700V |
| 7. | Hysteresis band (HB) | 0.5 |
| 8. | Proportional constant (kp) | 0.1 |
| 9. | Simulation time | 0.2s |
| 10. | Linear Load Details | R = 0.1 L = 1e-3 |

Table 7.3: System Parameter Values for Three Phase Active Power Filter

#### *1) Linear Load*



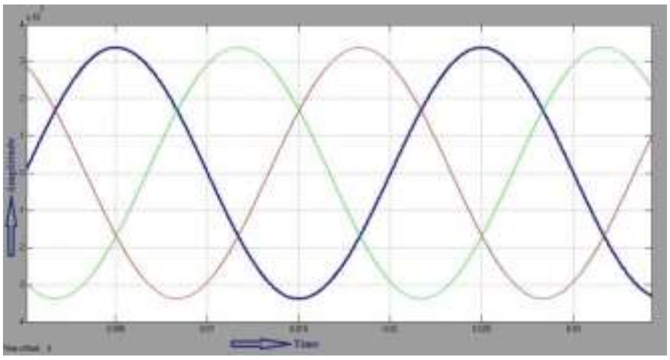


Fig. 18: Voltage & Current Source for Linear Load

Fig 17 presents the voltage & current source of three phase shunt active power filter for Linear Load.

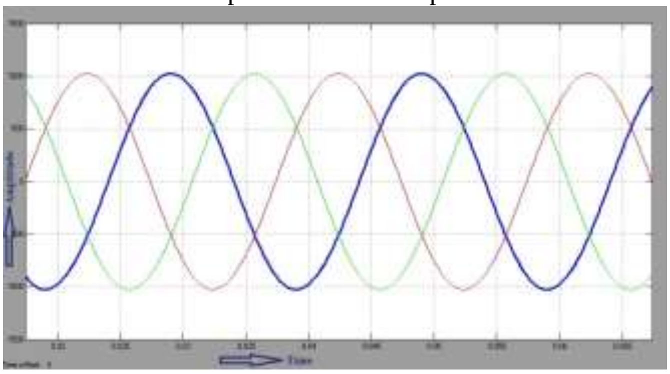


Fig. 19: Load Current for Linear Load

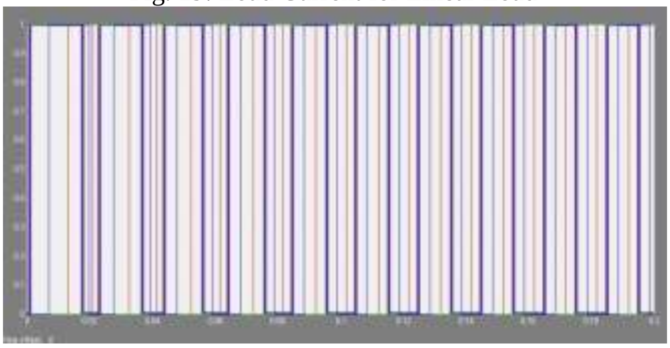


Fig. 20: Hysteresis Controller for Linear Load

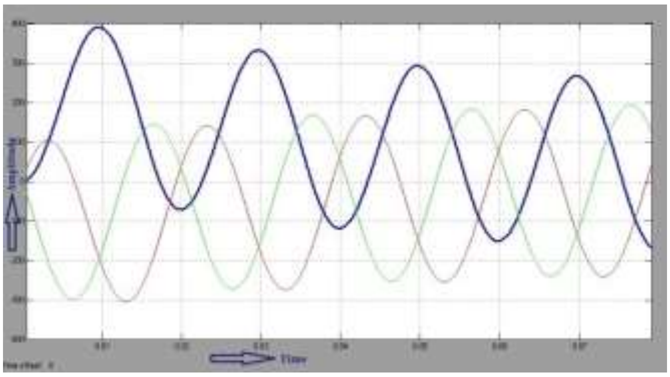


Fig. 21: Compensating current for Linear Load

## V. CONCLUSION

- In this research work single phase and three phase shunt active power filter have been designed and finally observed that three phase shunt active power filter gives better dynamic response than single phase shunt active power filter.
- In single phase shunt active power filter the THD of source voltage without compensation is 16.04% and after using our control strategy with compensation is 11.45%
- According to simulated responses the SAPF is found effective in injecting harmonic compensating current which reduces the source current THD and improves the power factor of the line.

- In single phase shunt active power filter the THD of Load current without compensation is 34.45% and after using our control strategy with compensation is 26.05%.
- In three phase shunt active power filter the THD of source voltage without compensation is 25.14% and after using our control strategy with compensation is 0.03% for Non Linear Load.
- In three phase shunt active power filter the THD of Load current without compensation is 54.82% and after using our control strategy with compensation is 3.74% for Non Linear Load

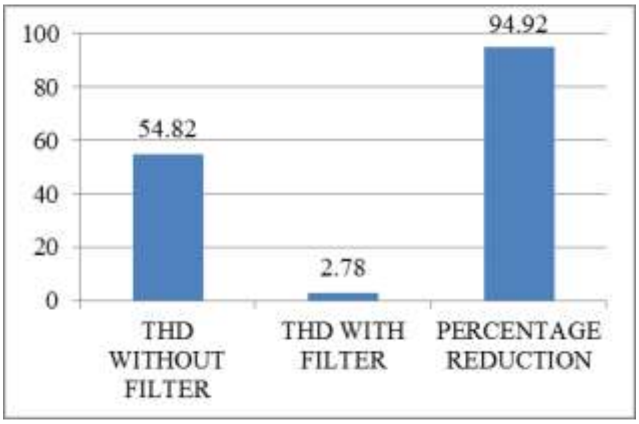



Fig. 22:

- In three phase shunt active power filter the THD of source voltage without compensation is 37.62% and after using our control strategy with compensation is 0.15% for Linear Load
- In three phase shunt active power filter the THD of Load current without compensation is 35.26% and after using our control strategy with compensation is 0.07% for Linear Load

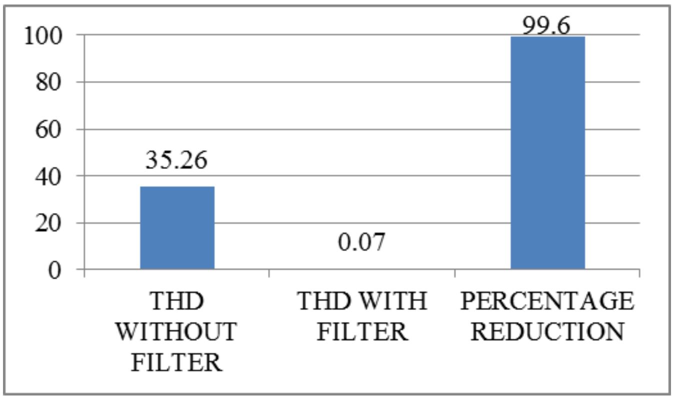



Fig. 23:

- The proposed scheme is easy for the implementation and can be applied effectively for both single phase and three phases shunt active power filters.
- In this research work indirect current control methods using equal current division technique has been applied to a shunt active power filter to compensate for reactive and harmonics currents.
- A simplified indirect control scheme is better than indirect control scheme. Indirect control scheme is an old method but simplified indirect control scheme is a new and advanced method because in this method we are using both controller PI controller and hysteresis controller.

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