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HARMONIC RESONANCE SUPRESSION USING AN ACTIVE FILTER IN A DISTRIBUTION POWER SYSTEM WITH FUZZY CONTROLLER

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ABSTRACT-An active filter with resonant current control is proposed in this paper to suppress harmonic resonance. The proposed hybrid filter is operated as variable harmonic conductance according to the voltage total harmonic distortion, so harmonic distortion can be reduced to an acceptable level in response to load change or parameter variation of power system. This harmonic distortion can be reduced by suppressing the harmonic resonance using the hybrid active filter, which is operated as variable harmonic conductance according to the voltage total; harmonic distortion. In proposed control method, reactive power compensation is achieved successfully with perceptible amount. The current control is realized by parallel-connected band-pass filters tuned at harmonic frequencies to ensure that the active filter functions as an approximately pure conductance. A shunt active filter operated as a harmonic conductance is able to suppress harmonic resonance in the distribution power system. Here we are using the fuzzy controller compared to other controllers i.e. The fuzzy controller is the most suitable for the human decision-making mechanism, providing the operation of an electronic system with decisions of experts. By using the simulation results we can analyze that the active filter with the resonant control provides better damping performance compared with other control methods.

Index Terms—Active filter, Fuzzy controller, harmonic resonance, resonant current control

I. INTRODUCTION

Harmonic distortion is fundamentally due to the tuned inactive channel and line inductance which produces resonances in the modern framework. To stifle this above issue crossover dynamic channel is utilized. Voltage distortion, because of consonant reverberation between control factor adjustment capacitors and line inductors, has gotten genuine worries in the conveyance control framework [1]. Tuned-inactive channels are normally received to adapt to symphonious issues, however their usefulness may experience the ill effects of part maturing, recurrence moving, or unexpected resonances. Along these lines, building alignment on uninvolved channels is often required to keep up their separating exhibitions.

The shunt dynamic channel controlled as a settled or variable conductance has been proposed to smother symphonious resonances in an outspread power conveyance framework [9]. In this manner the symphonious permission falls apart the damping execution of the dynamic channel, or even outcome in restoration of the "whack-a-mole" issue.

Damping execution of the dynamic channel is likewise investigated when distinctive current controls are actualized and when nonlinear burdens are conveyed at various areas. Different current control techniques have been proposed for dynamic power channels. Hysteresis current controller is least difficult, yet low-arrange music coming about because of variable exchanging recurrence may turn into a genuine concern [5]. Dreary control with specifically symphonious remuneration is exceptionally prominent. Notwithstanding, this approach may experience the ill effects of substantial registering stacking [7].

The resounding current controller is made out of different parallel-associated band-pass channels tuned at consonant frequencies to control the dynamic channel as an around unadulterated conductance. The dynamic channel with the full current control is proposed in this paper to stifle consonant resonances in the conveyance control framework.

OPERATION PRINCIPLE

A simplified one-line circuit graph of the proposed dynamic channel and the related control are appeared in Fig.1. The active filter unit (AFU) is introduced toward the finish of an outspread line to suppress harmonics. The AFU works as a variable conductance for various different frequency as given,

$$i^*_{abc,h} = \sum_h G^*_h . E_{abc,h} \qquad (1)$$

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where h represents the order of the harmonic frequency. The conductance command G∗ h is defined as a control gain to dampen harmonic voltage Eabch. As shown in Fig. 1, the control is composed of harmonic-voltage extraction and tuning control, followed by the current regulation and PWM algorithm. Operation principle and design consideration are given as follows.

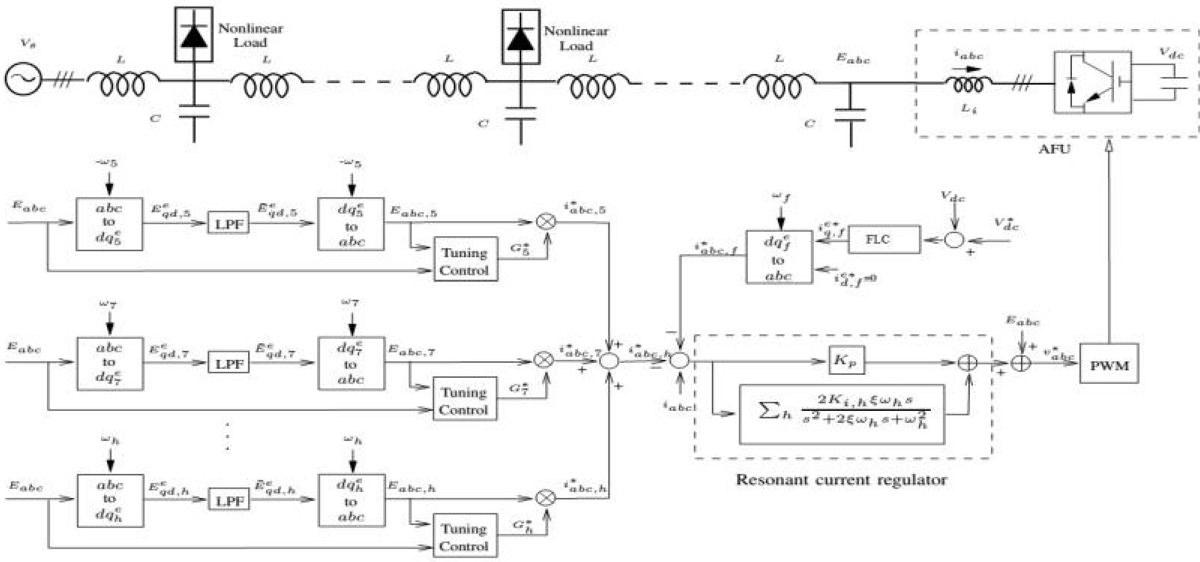

Fig. 1. Active filter and the associated control.

A. AFU control

Harmonic voltage on the special frequency is determined based at the so-called synchronous reference frame (SRF) transformation. The specific harmonic voltage issue becomes a dc price after Eabc is converted into the SRF at ωh, Accordingly, a low-pass filter out (LPF) is applied to split the dc cost and then the corresponding harmonic aspect E abc,h is obtained when applying opposite transformation. It is worth noting here that a phase-locked loop (PLL) is needed to decide machine frequency for implementation of SRF. ωh ought to be set as a poor value for poor-series issue.

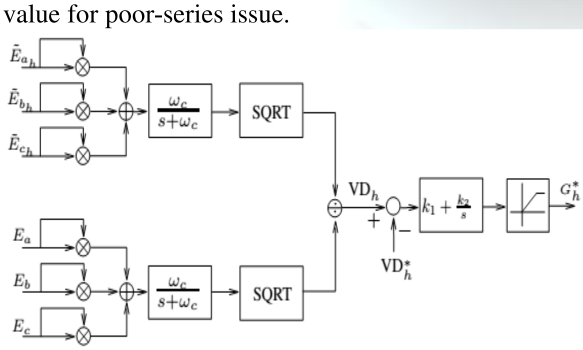

Fig. 2. Tuning control of the conductance command.

Fig. 2 suggests the tuning manage for the conductance command G∗ h. As illustrated, G∗h is decided in step with the harmonic voltage distortion VDh at the AFU installation point Eabc, wherein VDh is defined as the share ratio of the harmonic voltage thing Eh (rms price) to the voltage E (rms fee) by using

$$VD_h = \frac{E_{h,RMS}}{E_{RMS}} . 100\%$$

$$E_{h,RMS} = \sqrt{\frac{\int_t^{t+T}(E_{a,h}(t)^2+E_{b,h}(t)^2+E_{a,h}(t)^2)}{T}dt} \quad (2)$$

$$E_{RMS} = \sqrt{\frac{\int_t^{t+T}(E_{a,h}(t)^2+E_{b,h}(t)^2+E_{a,h}(t)^2)}{T}dt}$$

The derivation of VDh is about evaluated with the aid of the usage of two LPFs with reduce-off frequency at ωc, which can be to clear out ripple additives in the calculation.

The damping ratio ξ is designed to determine the selectivity and bandwidth of the contemporary manage. Accordingly, the voltage command vabc∗ is obtained for PWM to synthesize the output voltage of the energetic clear out.

B. Modelling of control

Nomenclature used on this segment is given as:

Vsh(s): harmonic voltage on the supply terminal

Eh(s): harmonic voltage at the installation area of the active filter

Ih(s) : harmonic contemporary of the energetic filter out

I∗ h(s) : harmonic modern-day command of the lively filter out.

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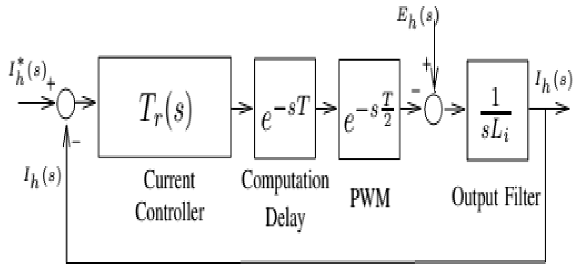


Fig. 3. Current control block diagram of the proposed AFU.

Fig. 3 shows modern-day manipulate block diagram for each segment. Digital sign processing delay and PWM put off are included, where T represents a sampling length.

Hence, contemporary loop stability and modern tracking capability may be truly evaluated by way of the use of bode plots of open-loop and closed-loop transfer features.

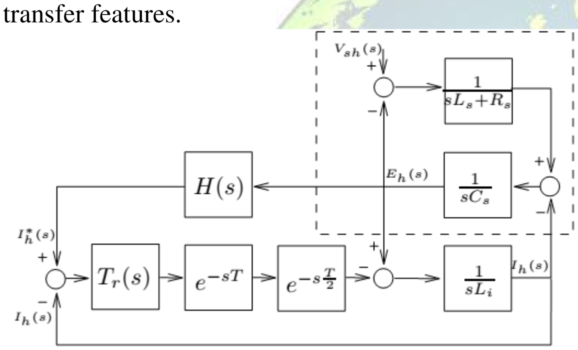


Fig. 4. Voltage control block diagram of the proposed AFU within the distributed electricity device.

Fig.4 shows the block diagram for harmonic damping evaluation. Since excessive-order harmonics seldom excite resonances, the distribution community is replaced with a 2nd order resonant tank (Ls, Cs, Rs) as indicated by using the dashed field. Here, the resonant tank is tuned to amplify the harmonic voltage Eh(s). Thus the damping performance of the AFU can be evaluated by means of the harmonic-voltage magnification shown in Fig. 4.

$$H(s) = G_h^* \frac{(s-j\omega_h)T_{LPF}}{1+(s-j\omega_h)T_{LPF}} \qquad (3)$$

II. HARMONIC RESONANCE

In this section, the line distributed-parameter model is applied to evaluate harmonic resonance along the feeder. A sample feeder given in TABLE I can amplify harmonic voltage if harmonic standing wave is generated [10]. The active filter is assumed to be installed at the end of the line (x = 9) with equivalent harmonic admittance Yh given in (5), where θh represents the lagging angle.

$$Y_h = |Y_h| < \theta_h \qquad (4)$$

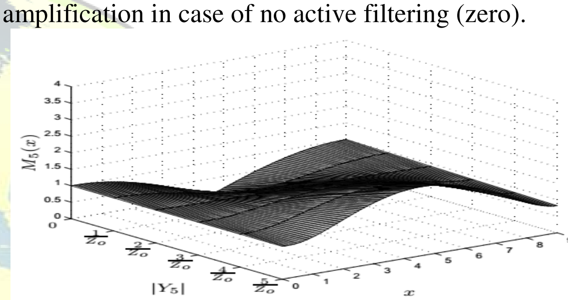
The voltage magnifying factor Mh(x) in (6) represents harmonic amplification along the feeder.

$$M_h(x) = \frac{|v_h(x)|}{|v_{s,h}|} \qquad (5)$$

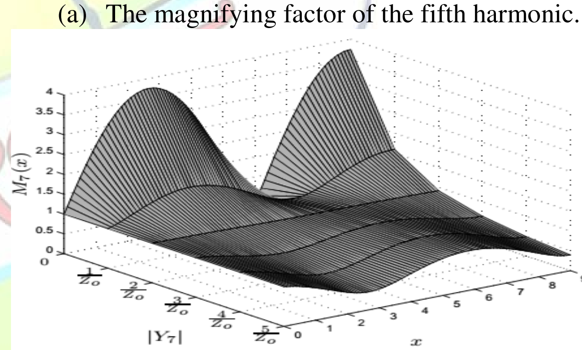
The suffix h denotes the order of harmonics, vh(x) is the harmonic voltage at function x(zero ≤ x ≤ 9), and vs,h is the harmonic voltage source (vs,h=vh(zero)). Note that Mh(x) may be formulated via the usage of standing wave equations considering both feeder and damping impedance supplied by the clear out.

A. Harmonic conductance

Fig. 5 indicates Mh along the line whilst the active clear out is modelled as a merely harmonic conductance, i.E. θh=zero. M5 shows no amplification in case of no active filtering (zero).



(a) The magnifying factor of the fifth harmonic.



(b) The magnifying aspect of the seventh harmonic.

Fig.5. The magnifying component alongside the radial line if the active filter out with θ = 0o.

However, M7 is strongly amplified due to seventh harmonic resonance as proven in Fig.Five(b). This outcomes from the status wave of seventh harmonics.
Harmonic admittance

Harmonic admittance

Fig. 6 and Fig. 7 show M5 and M7 when the active filter is modelled as harmonic admittance |Yh| with θ = −45o and θ = −90o, respectively.

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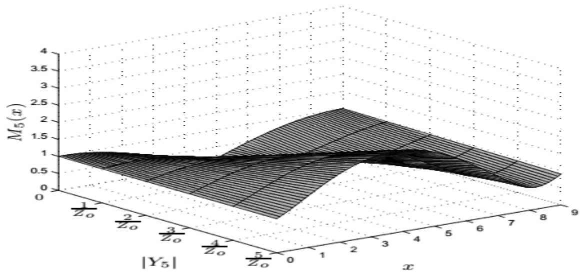
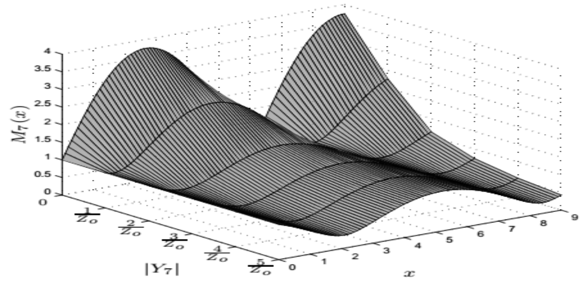
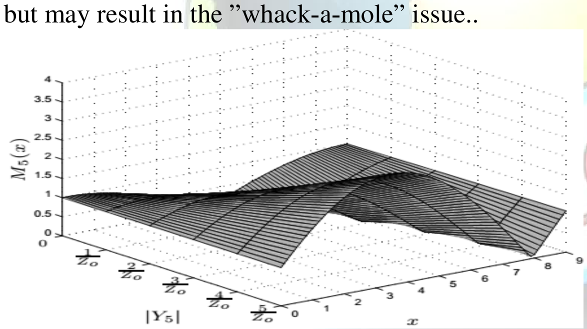


(a) The magnifying factor of the fifth harmonic for.

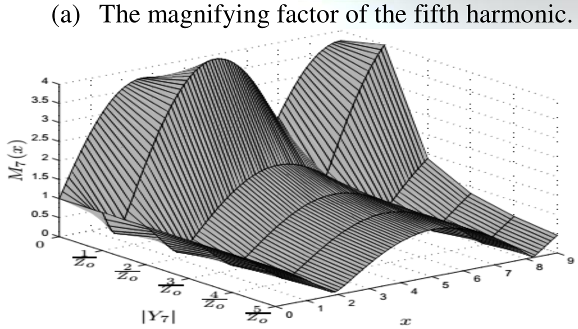


(b) The magnifying factor of the seventh harmonic.
Fig. 6. The magnifying factor along the radial line if the active filter is modelled as |Y| with θ = −45o

As observed, increasing |Yh| can enhance the damping capability at the end of the line only, but may result in the "whack-a-mole" issue..



(a) The magnifying factor of the fifth harmonic.



(b) The magnifying factor of the seventh harmonic.
Fig. 7. The magnifying factor along the radial line if the active filter is modelled as |Y| with θ = −90o.

Fig.7 shows voltage distortion close to the center phase of the line turns into a whole lot greater sizeable in case of θ = −90o. Therefore, the lively filter out operating as harmonic admittance might not effectively suppress harmonic resonances, or maybe set off different harmonic resonances at different locations at the feeder.

TABLE I
PARAMETERS OF AGIVENPOWERLINE

Line voltage	11.4kV
Line frequency	60Hz
Feeder length	9km
Line inductor	1.55mH/km(4.5%)
Line resistor	0.36Ω/km(1.2%)
Line capacitor	22.7μF/km(1.1%)
Characteristic impedance,Z_0	8.45Ω
Wavelength of 5^{th} hormonics, λ_5	17.8km
Wavelength of 5^{th} hormonics, λ_5	12.7km

III. FUZZY LOGIC CONTROLLER

In FLC, essential control activity is dictated by an arrangement of phonetic standards. These standards are controlled by the framework. Since the numerical factors are changed over into semantic factors, scientific displaying of the framework isn't required in FC.

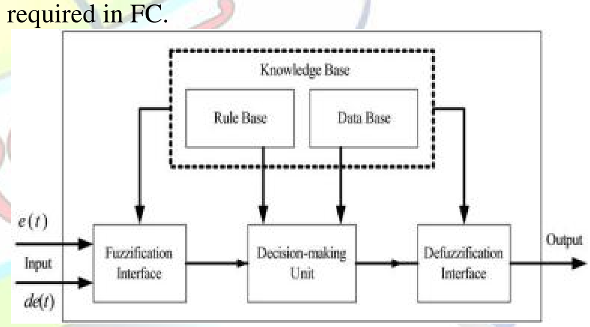


Fig.8.Fuzzy logic controller

The FLC involves three sections: fuzzification, obstruction motor and defuzzification. The FC is described as I. seven fluffy sets for each info and yield. ii. Triangular enrollment capacities for effortlessness. iii. Fuzzification utilizing consistent universe of talk. iv. Suggestion utilizing Mamdani's, 'min' administrator. v. Defuzzification utilizing the tallness strategy.

TABLE I: Fuzzy Rules

Change in error	**Error**						
	NB	**NM**	**NS**	**Z**	**PS**	**PM**	**PB**
NB	PB	PB	PB	PM	PM	PS	Z
NM	PB	PB	PM	PM	PS	Z	Z
NS	PB	PM	PS	PS	Z	NM	NB
Z	PB	PM	PS	PS	Z	NM	NB

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PS	PM	PS	Z	NS	NM	NB	NB
PM	PS	Z	NS	NM	NM	NB	NB
PB	Z	NS	NM	NM	NB	NB	NB

Fuzzification: Enrollment work esteems are doled out to the etymological factors, utilizing seven fluffy subsets: NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium), and PB (Positive Big). The Partition of fluffy subsets and the state of enrollment CE(k) E(k) work adjust the take care of business to fitting framework. The estimation of information mistake and change in blunder are standardized by an info scaling factor. In this framework the information scaling factor has been outlined with the end goal that information esteems are between - 1 and +1. The triangular state of the participation capacity of this plan presumes that for a specific E(k) contribution there is just a single predominant fluffy subset. The information blunder for the FLC is given as

$$E(k) = \frac{P_{ph(k)} - P_{ph(k-1)}}{V_{ph(k)} - V_{ph(k-1)}} \quad (7)$$

$$CE(k) = E(k) – E(k-1) \quad (8)$$

Inference Method: A few arrangement strategies, for example, Max– Min and Max-Dot have been proposed in the writing. In this paper Min technique is utilized. The yield enrollment capacity of each control is given by the base administrator and greatest administrator. Table 1 demonstrates control base of the FLC.

Defuzzification: As a plant more often than not requires a non-fluffy estimation of control, a defuzzification arrange is required. To register the yield of the FLC, „height" strategy is utilized and the FLC yield alters the control yield. Further, the yield of FLC controls the switch in the inverter. In UPQC, the dynamic power, receptive power, terminal voltage of the line and capacitor voltage are required to be kept up. Keeping in mind the end goal to control these parameters, they are detected and contrasted and the reference esteems. To accomplish this, the enrollment elements of FC are: mistake, change in blunder and yield. Christo Ananth et al.[8] discussed about E-plane and H-plane patterns which forms the basis of Microwave Engineering principles. The set of FC rules are derived from

$$u=-[\alpha E + (1-\alpha)*C] \quad (9)$$

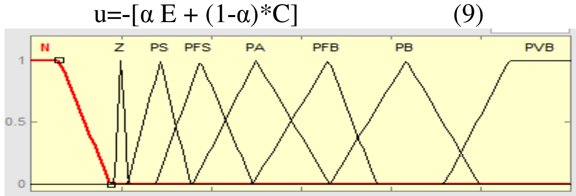

Fig 9. input error as membership functions

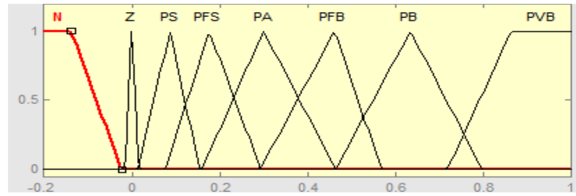

Fig 10. change as error membership functions

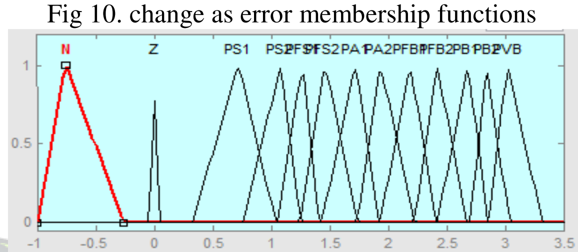

Fig.11 output variable Membership functions

Where α is self-adjustable factor which can regulate the whole operation. E is the error of the system, C is the change in error and u is the control variable.

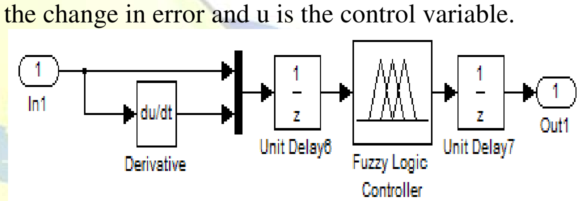

Fig 12.fuzzy logic controller in simulation

IV. SIMULATION RESULTS

In order to demonstrate harmonic damping overall performance, the lively clear out with the proposed manipulate is simulated with the aid of using the alternative brief program (ATP).

• Power system: 3φ, 220 V(line-to-line), 20 kVA, 60 Hz. Base values are indexed in TABLE II.

• Line parameters: L=3.1 %, C=13.7 %.

• Nonlinear loads: NL1 and NL2 are built by using three section diode-bridge rectifiers, and consume real electricity zero.25 pu, respectively.

• Linear loads: Both linear loads are to begin with off. LL1, LL2 are rated at 0.1 pu(pf=1.0), zero.09 pu(pf=zero.9), respectively.

• Current manipulate: okay p=25, ki,five=a hundred, ki,7=one hundred, ξ=0.01.

• Tuning manage: k1=100, k2=2000, ωc=62.8Rad/s, VD∗ h=three.Zero%.

• The AFU is carried out by way of a three-phase voltage supply inverter with PWM frequency 10 kHz.

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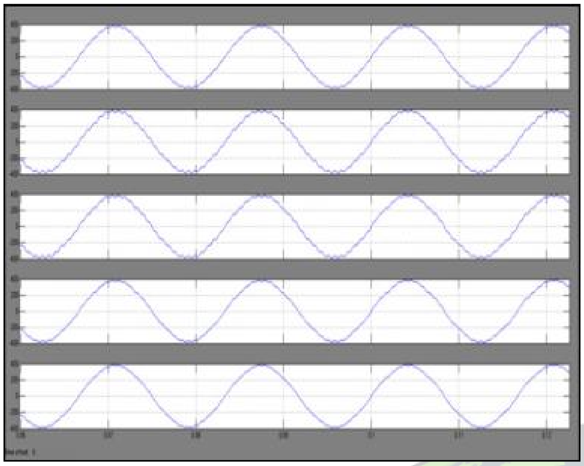
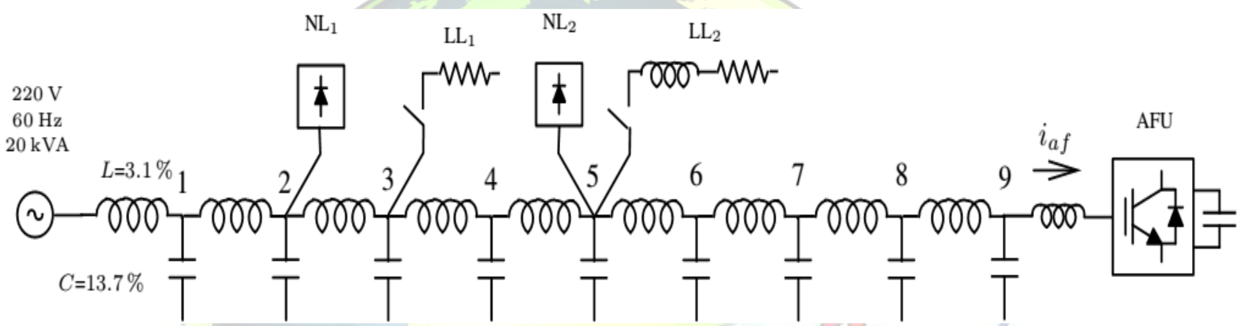
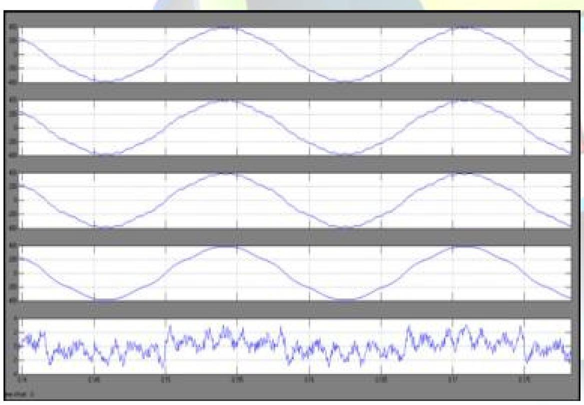


(b) AFU is off



(a) Simulation circuit configuration.



(c) AFU is on.

Fig. 13. Simulation circuit and steady-state results.

A. Steady-state results

Fig. 13(b) shows bus voltages are severely distorted before the AFU is initiated. For example, voltage THDs at bus 3 and bus 9 are 5.6% and 6.1%, respectively. Fig.14 illustrates voltage distortion VD5, VD7 on each bus. We can observe that voltage distortion along the line is cyclically amplified and seven harmonic resonance is dominant. This result confirms the previous analysis by harmonic distributed-parameter model

TABLE II
BASEVALUES

Voltage base	220v
Current base	52.5A
Impedance base	2.42Ω
Conductance base	$0.413\Omega^{-1}$

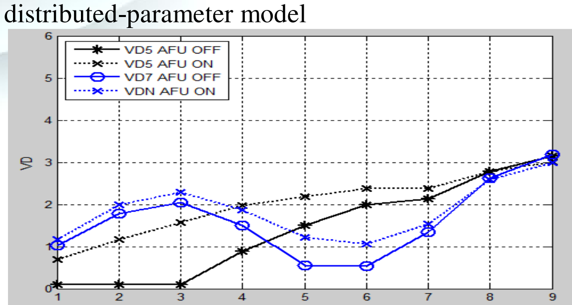


Fig. 14. VD5 and VD7 on all buses before and after the AFU is in operation.

Transient behavior

Fig. 15(a) shows temporary responses of voltage distortion whilst the AFU is off. Accordingly,

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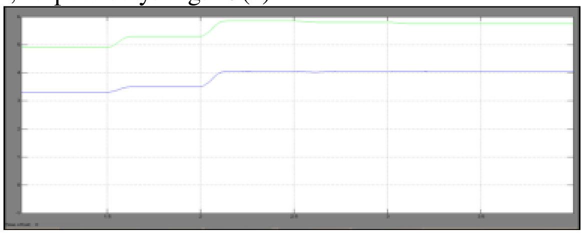
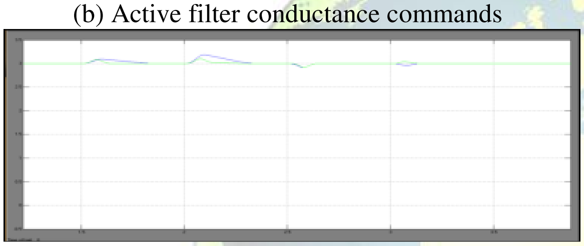
G∗five and G∗ 7 are reduced at t=2.Five s, t=three.0 s, respectively. Fig. 15(c)



(a) Harmonic voltage distortion when the AFU is off.

(b) Active filter conductance commands

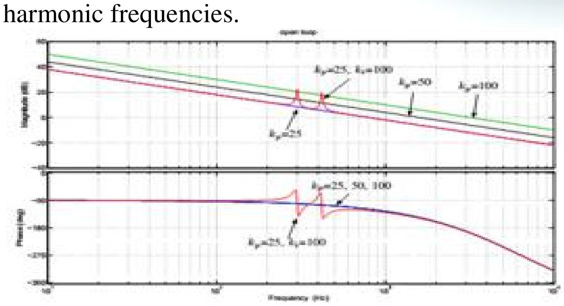


(c) Harmonic voltage distortion when the AFU is on.

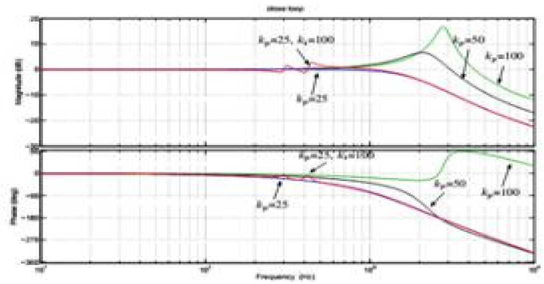
Fig. 15. AFU brief behavior (NL1, NL2 are extended at t=1.5 s, t=2.0 s, respectively, and then LL1, LL2 are turned on at t=2.5 s, t=3.Zero s, respectively.) suggests VD5, VD7 can be honestly maintained at 3% after quick transient.

B. Current-loop analysis

Fig. 16 shows the open-loop and closed-loop bode plots of the AFU modern-day manage. In Fig.15, there are magnitude peaks at both fifth and 7th harmonic frequencies as well as section-main repayment for the resonant modern manipulate. Therefore, the AFU is capable of function as an approximately pure conductance at fifth and seventh harmonic frequencies.



(a) Open-loop gain.



(b) Closed-loop gain.

Fig. 16. Bode plots of current loop for different current control methods.

Fig. 16 shows voltage THDs of time-domain simulations on all buses for different current control.

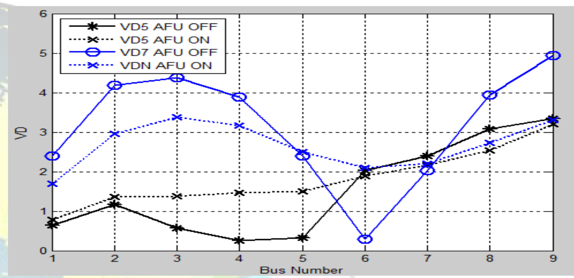


Fig. 17. Comparison of voltage THD for different current controls.

TABLE III summarizes conductance commands and AFU currents.

TABLE III
TEST RESULTS FOR DIFFERENT CURRENT CONTROLS

	G_5	G_7	RMS current
$k_p = 50$	1.89pu	1.04pu	7.8%
$k_p = 25$	3.39pu	0.90pu	12%
$k_p = 25$, $k_i = 100$	1.14pu	1.28pu	6%

B. Voltage damping analysis

Fig.18 indicates that 7th harmonic voltage is decreased and managed through harmonic conductance after the AFU is turned on. This test can affirm AFU effectiveness.

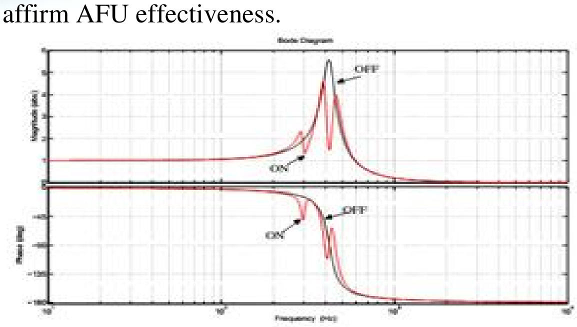


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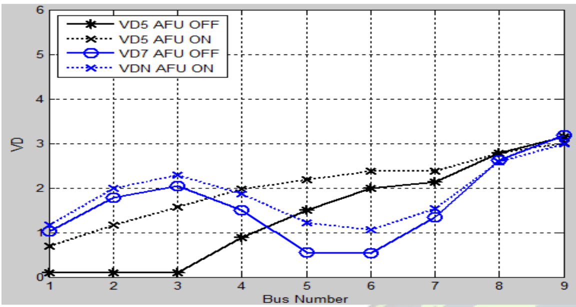
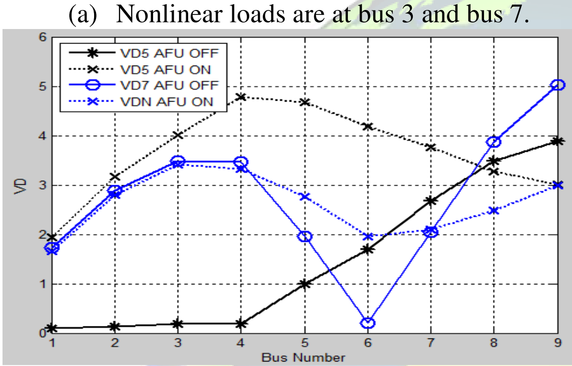
Fig. 18. Frequency characteristics of harmonic amplification.

C. Nonlinear loads at different locations

In this paper, the damping overall performance of the AFU is evaluated whilst nonlinear masses are related to exclusive locations



(a) Nonlinear loads are at bus 3 and bus 7.



(b)Nonlinear hundreds are at bus 4 and bus 6.

Fig. 19. Harmonic damping performances when nonlinear hundreds are linked to exclusive buses.

Fig. 19(a), Fig. 19(b) exhibit voltage distortion on all buses while nonlinear masses at bus 2,5 , bus three,7 , bus 4,6 , respectively. TABLE IV lists the corresponding G∗5 and G∗ 7, respectively.

TABLE IV
AFU CONDUCTANCECOMMANDS

	G_5^*	G_7^*
NLs at Bus 2,5	1.14pu	1.28pu
NLs at Bus 3,7	1.19pu	0.32pu
NLs at Bus 4,6	3.15pu	1.23pu

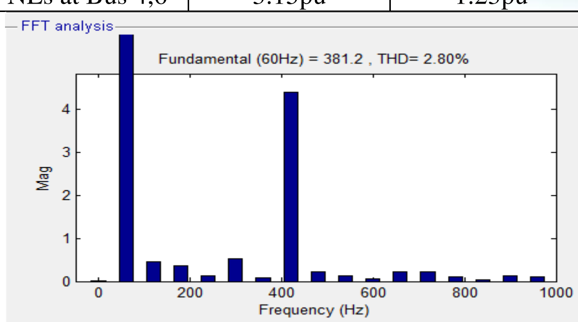


Fig.20 Total harmonic distortion with PI controller

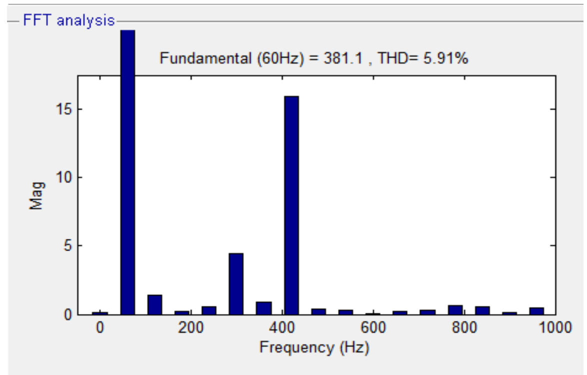


Fig. 21. Total harmonic distortion with fuzzy controller

TableV
Comparision between PI and Fuzzy controller

Controller	THD
PI	5.91
Fuzzy	2.80

VI. CONCLUSION

The proposed Active clear out is operated as variable harmonic conductance in step with the voltage overall harmonic distortion, so harmonic distortion may be reduced to an appropriate stage in response to load change or parameter variant of power system. By the usage of the bushy controller for a nonlinear system allows for a discount of unsure effects in the machine control and enhance the performance. The active filter with the resonant modern control is proposed on this paper to suppress harmonic resonances in the distribution strength machine. In FLC, fundamental manipulate motion is determined by way of a set of linguistic guidelines. These policies are determined by the system This harmonic distortion may be decreased with the aid of suppressing the harmonic resonance the usage of the lively filter, that's operated as variable harmonic conductance in keeping with the voltage total; harmonic distortion. Damping overall performance of the active filter is mentioned while nonlinear hundreds are placed at unique buses. The contemporary manage is applied by means of numerous parallel band-bypass filters tuned at harmonic frequencies so that the energetic filter can perform as an about natural harmonic conductance. Both modern loop and voltage loop are modelled to demonstrate present day-monitoring capability and damping overall performance of the active filter.

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