Enhanced Hybrid Power Grid System Using Adaptive Fuzzy Logic Controller by Supraharmonics Reduction

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Abstract: - Hybrid Systems meet the growing needs of electrical energy in the countries. The mismatching of hybrid systems leads to the phase shift in the three-phase signals, producing more harmonics in the band of 2 to 150kHz.However, due to various factors, harmonics have arisen from the RITHAPF and TCR which act as the phase shift controller in hybrid systems. Therefore, the Adaptive Fuzzy controller is employed with RITHAPF and TCR to maintain the phase shift and attenuate the harmonics produced. which outperforms the Hysteresis controller by 17.5% approx. in harmonic suppression and the simulation carried out for various phase angles

Key-Words: - Hybrid Power Electronics Adaptive Fuzzy Controller, Harmonics suppression, RITHAPF, *TCR*, Supraharmonics, Hybrid Active Filter.

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1 Introduction

Hybrid systems have evolved to combat the augmenting needs of electrical energy. Combining the output of different energy sources makes an uninterrupted power supply possible. This reduces the uncertainty of the power systems. This method increases reliability, reduces the dependence on a single source, and increases the system's overall efficiency. The role of power electronics is to condition, convert, and control of input energy sources to different forms. In hybrid systems, the role of power electronics is quite difficult. The downside of the hybrid systems is initial cost for installation, modelling, and accumulation of energy from various sources is a difficult task and maintaining the system. The hybrid sources are connected hence it is the need to address the issues in all ranges of the system to design an efficient power grid system.

The system quality depends on the amount and quality of the power generated. On the other hand quality of the signals affects the system's reliability. The harmonics formed due to the mismatch in the system is the main reason for the deteriorating signals. The harmonics are the signal waveform of integral multiples of the original frequency of the fundamental waveform. In power electronics the harmonics are the root cause of mismatched non-linear loads, high-frequency operation of power electronics devices, magnetic saturation produced in transformers, inductive devices, resonance caused due to the interaction of capacitors and inductors in the transformers, capacitors banks, and transmission lines, fault situations like short circuit and asymmetrical conditions like unbalanced loads. The harmonics produced range of 2 to 150kHz is called supraharmonics formed in the power grid system due to varying amounts of power obtained from the sources. When the hybrid sources are connected, it is important to address the supraharmonic suppression.

In the paper [1], the authors inscribed the importance of supra harmonics suppression to increase the system's power quality, hence the authors proposed the Hybrid Power Filter (HPF) contains active and passive parts in it. The active section works as the linear power amplifier which suppresses the high frequency component harmonics and the passive section reduces the fundamental frequency component harmonics. A detailed review of harmonic sources is done in the paper [2] where the authors presented a detailed study of sources like electric vehicle sources, green energy generation sources, electric arc furnace loads, residential loads, and electric vehicular loads. The authors of this paper gave good guidance of the modern power systems and its negative impact overcoming too. The micro-grid systems contain the Voltage Source Converter (VSC), where the current and voltage harmonics takes place that results in the negative impact of the whole system performance is explained in the paper [3] by stochastic modelling. The paper [4] is presented by IEEE PES Renewable technologies to address the recent issues in the power electronics systems like configurations, unit measures, energy management and control, etc to maintain the power grid systems' energy sustainability. The Artificial Intelligence based Neural Network (ANN) and fuzzy based Adaptive Neuro Fuzzy Inference Systems (ANFIS) are proposed for two models of hybrid power grid systems like wind and solar renewable sources for simulation in the paper [5] and the 11th and 13th harmonic distortion is taken for simulation that shown ANFIS is efficient in both the hybrid system models.

In the papers [6], [8]-[11], Adaptive Fuzzy Controllers (AFC) is used for the harmonic suppression in the hybrid grid system. The power factor is obtained closely to one value and the Total Harmonic Distortion (THD) is controlled using the PSO-based adaptive fuzzy controller in the Hybrid Active Filter (HAPF). In the paper [8], an adaptive fuzzy hysteresis current-controlled active power filter in hybrid shunt configuration is proposed for power compensation in reactive components and harmonic distortion range which uses the low-rated elements like active power filter and shunt passive filters. The paper [9] used Active Power Filter (APF) and Passive Power Filter (PPF) in series to the power grid system and uses the Adaptive Fuzzy controller using PI is proposed which attenuates by matching the magnitude of frequency of APF and PPF. The Multi-Objective Genetic Algorithm (MOGA) based AFC is proposed by the authors in the paper [10] for harmonics mitigation in Photovoltaic Renewable Energy Sources (RES) using APF. The effects of torque ripple, eddy current loss, and average torque were also demonstrated. DC De-icing model with an active filter and an AFLC is proposed for four substations of 220KV is presented in the paper [11] which attenuates the harmonics efficiently.

The paper [7] discusses the topics on the kinds of harmonic and inter-harmonic for different frequency groupings of the power systems and comparison using Total Harmonic Distortion (THD) parameter is used for assessing the power inverters is made. The fuzzy based optimisation is chosen in the papers [12], [17-20], using active filter, passive filters and optimization technique to reduce the harmonics of the power grid systems. The reason for harmonics in the converter and inverters are mainly due to the small signal stability issues is addressed in the paper [13]. This paper derives the systematic transfer function for harmonics in small signal analysis for linear models ac-dc converters. The nonlinear loads and Hybrid Passive Filter (HPF) are used to mitigate the harmonics present in voltage and current of the power system. Constrained Optimization is used for tunning the parameters of HPF is done to attenuate the harmonics. The harmonics produced due to unreasonable resonance occurred in the passive filter and line inductances are addressed in the paper [15] which is combated using the variable conductance tunning-based hybrid filters which employs the 7th order tuned passive filter and active filter in serial connection with source. The adaptive hysteresis current control and Synchronous Reference Frame is used for the reference signal generation of controller for current signals is proposed in the paper [16] along with the hybrid active power filters which reduces the THD range of the system effectively.

From the review it is identified that harmonic distortion deteriotes the quality of the signals. In the hybrid systems due to mismatch of the signals more harmonic distortions are present. This paper concentrates on the supraharmonics which is present due to the backslide of the Resonance based Impedance Type Hybrid Active Filter (RITHAPF) and Thyristor Controlled Reactor (TCR) of the hybrid system which is overcome using the Adaptive Fuzzy Controller (AFC).

2 Analysis of Total Harmonic Distortion (THD)

The harmonics in general is the waved whose frequency is the integral multiple of the fundamental frequency of the reference signal. The harmonics are usually unintentionally produced waveforms from the converter and inverter of the power electronic systems. In order to attenuate this unwanted signal, a clear calculation of amount of harmonics present in the system is required which is defined by the term THD. The THD is mathematically defined by ratio of sum of Root Mean Square (RMS) of all the harmonics present in the system to the fundamental RMS of the signal which is given in the (1),

$$THD = \frac{\sqrt{V_2+V_3+\cdots\ldots+V_N}}{V_1} \quad (1)$$

where V_1 is the fundamental frequency

V_2, V_3, ….V_n are the harmonics frequencies

3. Hybrid Power Electronics System

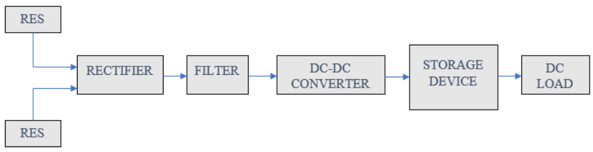


Fig. 1 Hybrid Power Electronics System Block Diagram

Figure 1 shows a Hybrid Power Electronics System (HPES) consisting of two input Renewable Energy Sources (RES) may be wind turbines, solar, geothermal, tidal energy etc. Hybrid systems are employed to overcome the dependency on a single source and to meet the needs of electrical energy due to more applications and a growing population. The energy from both the system are given as input to rectifiers which convert ac to dc signals. Then the signals are sent to the filter which may be active or passive that is depends on the application and design. The converter in the block diagram helps to increase the gain of the input signal using the high-gain dc-dc converters which is of less cost and boosts the input of the hybrid systems using the boost converter and an inductor. Then the energy is stored in the storage device for the future use. The stored energy is supplied to different kinds of loads according to the application. For the compensation of adverse effects the Resonant Impedance Type Hybrid Active Filter and Thyristor controller Rectifier (TCR) are involved. Figure 2 represents the configuration diagram of the hybrid model.

The Thyristor Controlled Reactor (TCR) [22] is the device used in the power electronics for controlling the phase of the signals according to the varying load conditions. It is made of reactance which effectively varies from zero to desired value according to the loads with the help of thyristor valve. The firing angle theoretically between 90° to 180° but in practical little deviations are present. The major disadvantage of the TCR is it cannot promptly switch between ON and OFF conditions this leads to the generation of harmonics. This is mainly due to reactive component present in the circuit. The instantaneous TCR current equation is given in the (2),

$$i(t) = \frac{v_{rms}}{2\pi f l}(\cos\alpha - \cos 180) \quad (2)$$

On the other hand, the Resonance based Impedance Type Hybrid Active Filter (RITHAPF) [21]is of active elements and passive elements for filtering purposes. The reactive components present in this filter leads to the phase shift of the fundamental signal which gets added or subtracted with the fundamental signals leads to the generation of harmonic waves. The RITHAPF has good advantage for matching the loads but its main drawback is the phase shift happening in the filtered signal.

4. Proposed Model

Adaptive Fuzzy Controller (AFC) is the enhanced version of the fuzzification and defuzzification process which functions in a compatible manner to the system. Its main principle is adjusting the parameters according to the needs of the system. The three steps of AFC [23] is collecting the data samples, adjusting of controller parameters and enhancing the controller efficiency. The Figure 3 represents the proposed model where the AFC is used in RITHAPF and TCR to reduce the harmonics.

RITHAPF Harmonic Suppression

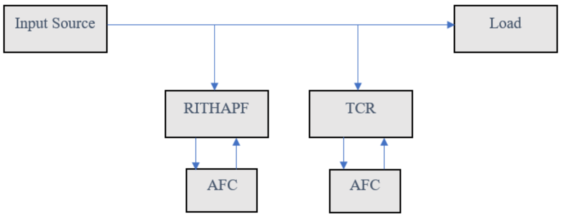


Fig. 3 Proposed System Model

Let us consider the input signals be x_1, x_2 …..x_n and the phases of the signals are represented by α_1, α_2….. α_N. Using the Adaptive Fuzzy Controller, the error in the phase of the signal with the fundamental frequency is calculated using the equation (3),

$$e(t) = \alpha_1(t) - \alpha_n(t) \qquad (3)$$

$where\ \alpha_n(t)$ is the nth harmonics of the input signal.

From the value of error, e(t), the adjusting parameter 'k' is derived by the Adaptive Fuzzy Controller depends on the phase shift taken in the input signal with respect to the fundamental frequency. The 'K' parameters consist of $K_1, K_2, \ldots K_n$ values based on the fuzzification required for every input signal. The output of the AFC is given by the equation,

$$\gamma(t) = x_1(t) + \mu(t) \qquad (4)$$

Where K= k_1, k_2,…..k_n are adjusting parameters of Adaptive Fuzzy Controller and the function of μ(t) is given by,

$$\mu(t) = k_1\alpha_2 + k_2\alpha_3 + \cdots + k_n\alpha_{n+1} \qquad (5)$$

The formula for generalized phase value is given by,

$$\alpha = tan^{-1}(\frac{X_L - X_C}{R}) \qquad (6)$$

Where the X_L and X_C are the reactance and R is the resistance of the Filter.

The Adaptive Fuzzy Logic Control is given by,

$$K = \theta(e(t)) \qquad (7)$$

Thus by obtaining the 'K' adjusting parameter values after fuzzification the output of the fuzzy controller produces the signals in the fundamental frequency which reduces the formation of harmonic signals in the RITHAPF filter of the Hybrid Active Filter.

4.1 TCR Harmonic Suppression

In the Thyristor Controlled Reactor, the Adaptive Fuzzy Controller shifts the phase of the signals either in the 90° or 180° to maintain the phase variation in order to reduce the harmonics. The Adaptive Fuzzy Controller function for TCR is given by,

$$K = \varphi(f(t)) \qquad (8)$$

Where f(t) is the error function obtained from the signal.

$$f(t) = \cos(360° - \emptyset) \qquad (9)$$

The output of Adaptive Fuzzy Controller for TCR is given by,

$$\gamma(t) = x_1(t) + \beta(t) \qquad (10)$$

Where the β(t) is the adjusted signals obtained by fuzzification.

$$\beta(t) = x_2 cos\gamma_2(t) + x_3 cos\gamma_3(t) + \cdots + x_n cos\gamma_n(t) \tag{11}$$

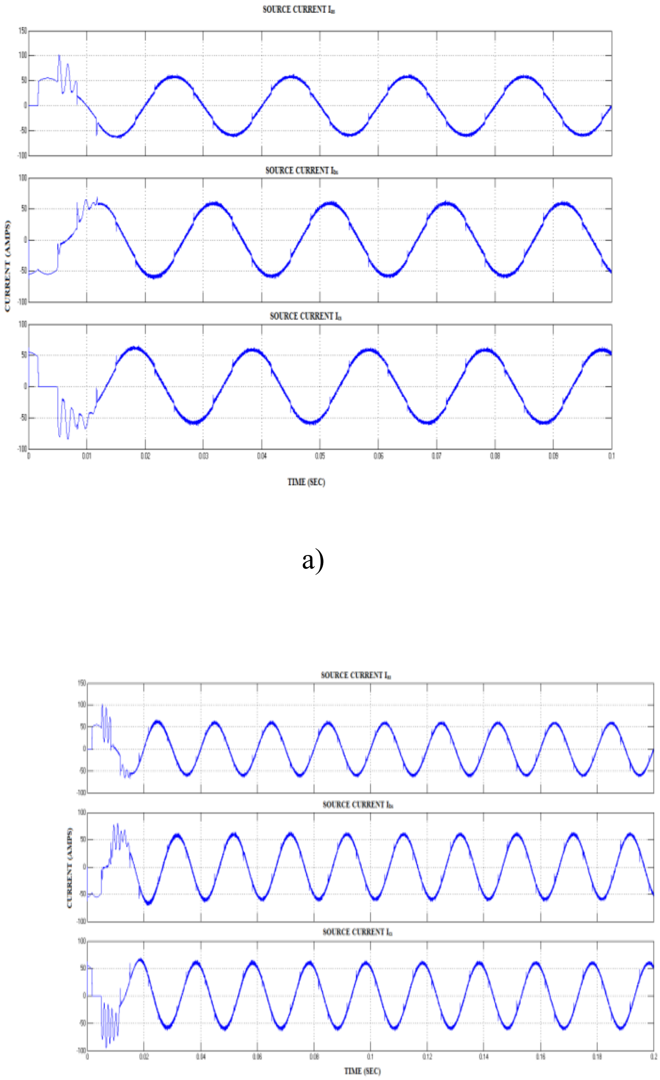
Therefore the fuzzification and the defuzzification is carried out sum of all the signals which results in high voltage gain without the harmonics.

5. Implications

Table 1 Simulation Parameters

Variables	Values
Fundamental Frequency (f)	50Hz
Impedance	0.01+0.000001Ω
Inductor	2mH
Capacitor	20µF
TCR	5H
Line voltage	400V
Load	1000 Ω

The proposed work is processed using the MATLAB and SIMULINK software using the simulation parameters discussed in the table 1. In the Figure 4 the simulation is carried out for AFC and hysteresis controller for Power Electronics Hybrid Systems. The Hysteresis controller is conventional method for reducing the harmonics of the system by increasing the voltage in the hysteresis band. The input source voltage of 400V with the fundamental frequency 50Hz is given as input to the PEHS. The TCR of 5H is used and the inductor and capacitor of 2mH and 20µF is used in RIPTHAF filter.

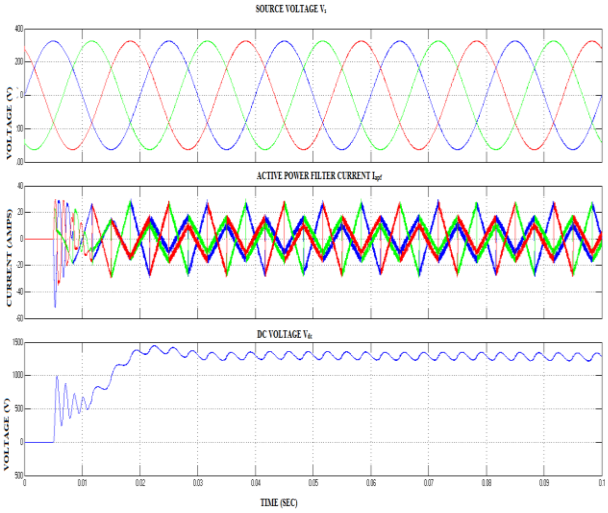


a)

b)

Fig. 5 Input waveform of a) Hysteresis Controller and b) Adaptive Fuzzy Controller

The Figure 5 shows the input waveform of three phase line system of the hybrid system using the Hysteresis and Adaptive Fuzzy Controller. From the waveform of both controllers, it is seen that the harmonics present in the input waveform reduced in the proposed work where their smooth waveform is obtained without harmonics. This is done with the help of maintaining the constant phase shift among the three phase signals which results in the harmonic attenuations both by RITHAPF and TCR in the PEHS using AFC.



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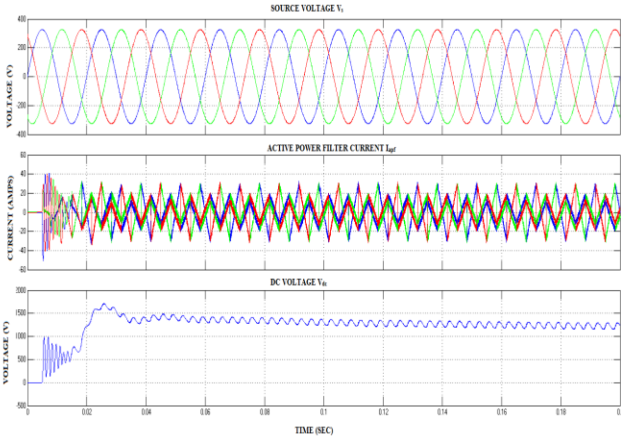
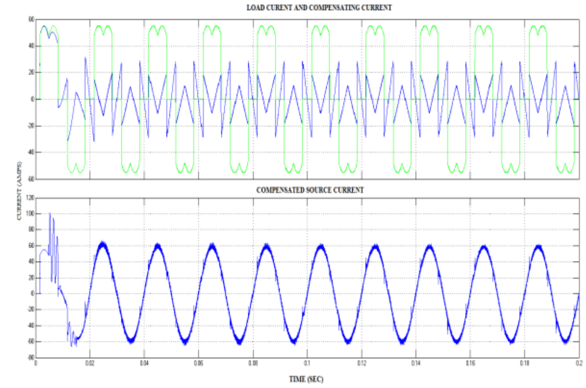


b)

Fig. 6. Representation of V_s, I_{APF} and V_{dc} of a) Hysteresis Controller b) Adaptive Fuzzy Controller

Figure 6 depicts the waveforms of source voltage, Active Power Filter current and dc voltage of the hysteresis controller and Adaptive Fuzzy Controller. In the AFC voltage source waveform, the phase shift is maintained at regular intervals with the smooth waveform and the current waveform of filter has less harmonics compared to the hysteresis controller. On visualising the dc voltage waveforms, the AFC based PEHS attains constant output at less time compared to the hysteresis controller. Figure 7 is the output load current and compensation current waveform of the hysteresis controller and AFC. The hysteresis controller load output is not constant with more harmonics compared to the AFC.

The Figure 8 is the representation of frequency domain analysis of hysteresis and AFC controller using Fast Fourier Transform analysis where the AFC shown 4.42% reduction in harmonics compared to Hysteresis controller by maintaining the appropriate phase of the signals irrespective of the operation it is carried out.



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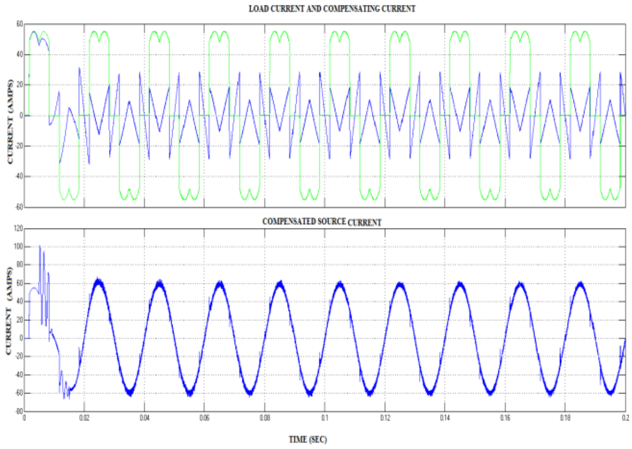


b)

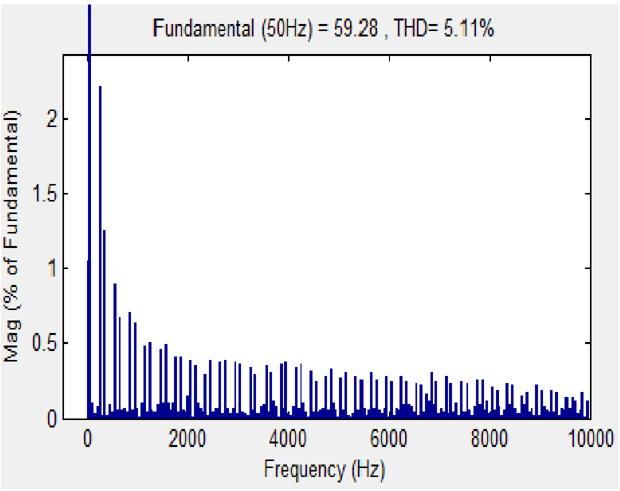
Fig. 7 Representation of I_L and I_{comp} of a) Hysteresis Controller b) Adaptive Fuzzy Controller

Table 2 Simulation Results for Three Different Phase shifts

S. No	Phase Variations	Variables	THD	
			Hysteresis	AFC
1	0°	V_s	5. 09%	4.5%
		I_s	0.23%	0.20%
		I_{APF}	30%	30.27%
		I_{comp}	4.9%	4.02%
2	90°	V_s	5.13%	5.02%
		I_s	0.19%	0.17%
		I_{APF}	29.96%	29.75%
		I_{comp}	5.1%	4.8%

3	180°	V_s	4.9%	4.02%
		I_s	0.23%	0.19%
		I_{APF}	31.15%	30.65%
		I_{comp}	5.51%	4.92%

The Table 2 is the simulation obtained from by changing the phase degree of the input waveforms to study the proposed model resilience towards practical scenario. It is seen that for all the phase shift of 0°, 90° and 180°, there is the little variations in the output and maintains the THD suppression at approximately same range. The difference in the THD of Hysteresis controller and the AFC also shown constant output of 17.5% approximately.



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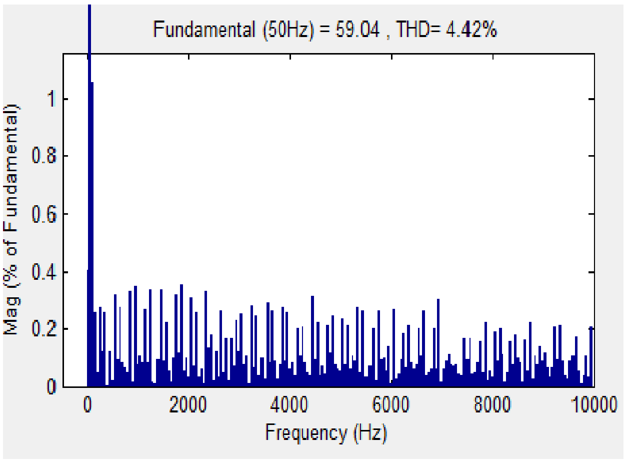

b)

Fig 8. Frequency Domain Analysis of a) Hysteresis Controller b) Adaptive Fuzzy Controller.

6 Conclusion

The proposed work of employing Adaptive Fuzzy Controller in the RITHAPF and TCR is done to reduce the supraharmonic present in the system due to the mismatch of elemets or loads present in the system. The mathematical analysis for the proposed work is presented. The SIMULINK is used to represent the proposed work where the outputs are provided in the implication part. From the outputs obtained it is seen that the Adaptive Fuzzy Controller outperforms the Hysteresis Controller which are depicted in the sourece voltage, load current , filter current, compensation current output waveforms. The phase shist is maintained appropraite in three phase of the signals so that the harmonics are reduced in the frequency range of 2 to 150kHZ. The FFT analysis also done which shown 17.41% higher efficiency in the harmonic attenuation compared to the Hysteresis controller.

References:

[1] *J. Li, Y. He, L. Xu and J. Liu*, "Design of Hybrid Power Filters for Supraharmonics Suppression in Power Electronics Dominated Power Systems," in *IEEE Journal of Emerging and Selected Topics in Power Electronics*, **Vol 12**, no. 2, pp. 2163-2175, April 2024, doi: 10.1109/JESTPE.2024.3365167.

[2] *Zhe Hu, Yang Han, Amr S. Zalhaf, Siyu Zhou, Ensheng Zhao, Ping Yang,* “Harmonic Sources Modeling and Characterization in Modern Power Systems: A Comprehensive Overview”, Electric Power Systems Research, **Vol 218**, 2023, 109234, ISSN 0378-7796, https://doi.org/10.1016/j.epsr.2023.109234.

[3] *Kuralkar, V. P. ., Khampariya, P. ., & Bakre, S. M., “*A Survey on the Investigation and Analysis for a Power System (Micro- Grid) with Stochastic Harmonic Distortion of Multiple Converters”, *International Journal of Intelligent Systems and Applications in Engineering*, *11*(3s), pp. 72–84, 2023. https://www.ijisae.org/index.php/IJISAE/article/view/2533

[4] *M. H. Nehrir* et al., "A Review of Hybrid Renewable/Alternative Energy Systems for Electric Power Generation: Configurations, Control, and Applications," in *IEEE Transactions on Sustainable Energy*, **Vol 2**, no. 4, pp. 392-403, Oct. 2011, doi: 10.1109/TSTE.2011.2157540

[5] *F. M. A. Hadi, H. H. Aly and T. Little,* "Harmonics Forecasting of Wind and Solar Hybrid Model Driven by DFIG and PMSG Using ANN and ANFIS," in *IEEE Access*, **Vol 11**, pp. 55413-55424, 2023, doi: 10.1109/ACCESS.2023.3253047.

[6] *Rafique, Waleed & Khan, Ayesha & Almogren, Ahmad & Arshad, Jehangir & Yousaf, Adnan & Jaffery, Mujtaba & Rehman, Ateeq & Shafiq, Muhammad, "*Adaptive Fuzzy Logic Controller for Harmonics Mitigation Using Particle Swarm Optimization", Computers, Materials and Continua. **Vol 71**. pp. 4275-4293, 2022. 10.32604/cmc.2022.023588.

[7] *Arranz-Gimon, A.; Zorita-Lamadrid, A.; Morinigo-Sotelo, D.; Duque-Perez,* O." A Review of Total Harmonic Distortion Factors for the Measurement of Harmonic and Interharmonic Pollution in Modern Power Systems", *Energies* 2021, **Vol *14***, pp.6467. https://doi.org/10.3390/en14206467

[8] *Mishra, Alok & Ray, Prakash & Mallick, Ranjan & Mohanty, Asit & Das, Soumya Ranjan.*, "Adaptive fuzzy controlled hybrid shunt active power filter for power quality enhancement" Neural Computing and Applications. **Vol 33**. 2021. 10.1007/s00521-020-05027-x.

[9] *Yasin, Mohammed & Abdul Abbas, Ali & Jasim, Ahmed, "*Adaptive Fuzzy Logic Control of Hybrid, Active Power Filters, for Harmonic Mitigation", IOP Conference Series: Materials Science and Engineering, 2020. 881. 012151. 10.1088/1757-899X/881/1/012151.

[10] *Elgammal, Adel & Boodoo, Curtis,"* Optimal Hybrid Filtering Strategy Using Adaptive Genetic-Fuzzy Logic Control for Harmonics Reduction in a Standalone Micro Hydroelectric Power Plant Coordinated with a PV System", European Journal of Electrical Engineering and Computer Science. **Vol 5**, pp.56-62, 2020. 10.24018/ejece.2021.5.4.348.

[11] *H. Foudeh and A. S. Mokhtar*, "Elimination of total harmonic distortion in transmission lines using adaptive fuzzy logic in de-icing process," *2015 9th Jordanian International Electrical and Electronics Engineering Conference (JIEEEC)*, Amman, Jordan, 2015, pp. 1-6, doi: 10.1109/JIEEEC.2015.7470752.

[12] *Rachid, Dehini & Ferdi, Brahim & Bekkouche, Benaissa.*," Fuzzy Logic Controller Optimization Based on GA for Harmonic Mitigation". Journal of Artificial Intelligence. **Vol 5**. pp 26-36, 2012. 10.3923/jai.2012.26.36.

[13] *X. Wang and F. Blaabjerg*, "Harmonic Stability in Power Electronic-Based Power Systems: Concept, Modeling, and Analysis," in *IEEE Transactions on Smart Grid*, **Vol 10**, no. 3, pp. 2858-2870, May 2019, doi: 10.1109/TSG.2018.2812712.

[14] *A. F. Zobaa and S. H. E. Abdel Aleem*, "A New Approach for Harmonic Distortion Minimization in Power Systems Supplying Nonlinear Loads," in *IEEE Transactions on Industrial Informatics*, V**ol 10**, no. 2, pp. 1401-1412, May 2014, doi: 10.1109/TII.2014.2307196.

[15] *T-L. Lee, Y. -C. Wang, J. -C. Li and J. M. Guerrero*, "Hybrid Active Filter With Variable Conductance for Harmonic Resonance Suppression in Industrial Power Systems," in *IEEE Transactions on Industrial Electronics*, **Vol 62**, no. 2, pp. 746-756, Feb. 2015, doi: 10.1109/TIE.2014.2347008.

[16] *Bhattacharjee, Kakoli.*, "Harmonic mitigation by SRF theory based active power filter using adaptive hysteresis control", 2014 Power and Energy Systems Conference: Towards Sustainable Energy, PESTSE 2014. 10.1109/PESTSE.2014.6805317.

[17] *Ghasemi, Ahmad & Mortazavi, S. & Kianinezhad, Reza,*" Fuzzy Logic Controlled Adaptive Active Power Filter for Harmonics Minimization and Reactive Power Compensation under Fast Load Variation", **Vol 3**, no.05, May 2008.

[18] *Pi, Karuppanan & Mahapatra, Kamalakanta*. PI and fuzzy logic controllers for shunt Active Power Filter--a report. ISA transactions. **Vol 51**. 163-9. 10.1016/j.isatra.2011.09.004, 2012.

[19] *Yellasiri, Suresh & Panda, Anup & Mikkili, Suresh.*. Real-time implementation of adaptive fuzzy hysteresis-band current control technique for shunt active power filter. Power Electronics, IET. **Vol 5**. 1188-1195. 10.1049/iet-pel.2011.0371,2012.

[20] *Kaliyamoorthy, Ananthi & Manoharan, S.*, "Power quality improvement using fuzzy logic controller based hybrid active power filter", International Journal of Innovative Technology and Exploring Engineering, **Vol 8,** pp. 245-248, 2019.

[21] *L. Chen, Y. Xie, Z. Zhang and J. Le*, "Compensation characteristics of resonant impedance type Series Hybrid Active Power Filter," *2009 International Conference on Electrical Machines and Systems*, Tokyo, Japan, 2009, pp. 1-5, doi: 10.1109/ICEMS.2009.5382692.

[22] *Abedeladim A. Mohamed Moftah;Zakariya Rajab;Ibrahim Ighneiwa*, " Investigation in Thyristor-Controlled Reactor (TCR)", *Proceedings of the 6th International Conference on Engineering & MIS 2020*. doi:10.1145/3410352.3410795

[23] *Dhinakar Pazhani*, Deivasigamani, S, K. A Ahamed Kandu Sahib, P.Senthilkumar,* "A Novel Battery Charging In Electric Vehicle Using Non Isolated Zeta Converter", Solid State Technology, ISSN:0038-111X, **Vol 63**, No 6 (2020), pp. 22225-22234..

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

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Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

Appendix

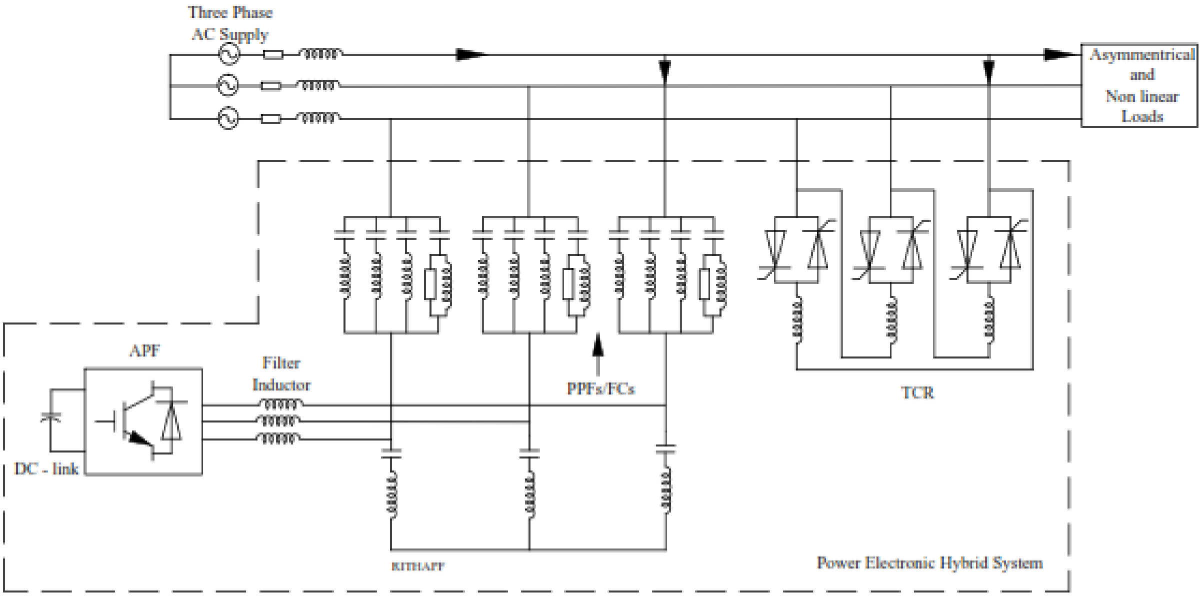

Fig. 2 Hybrid Power Electronic System Configuration

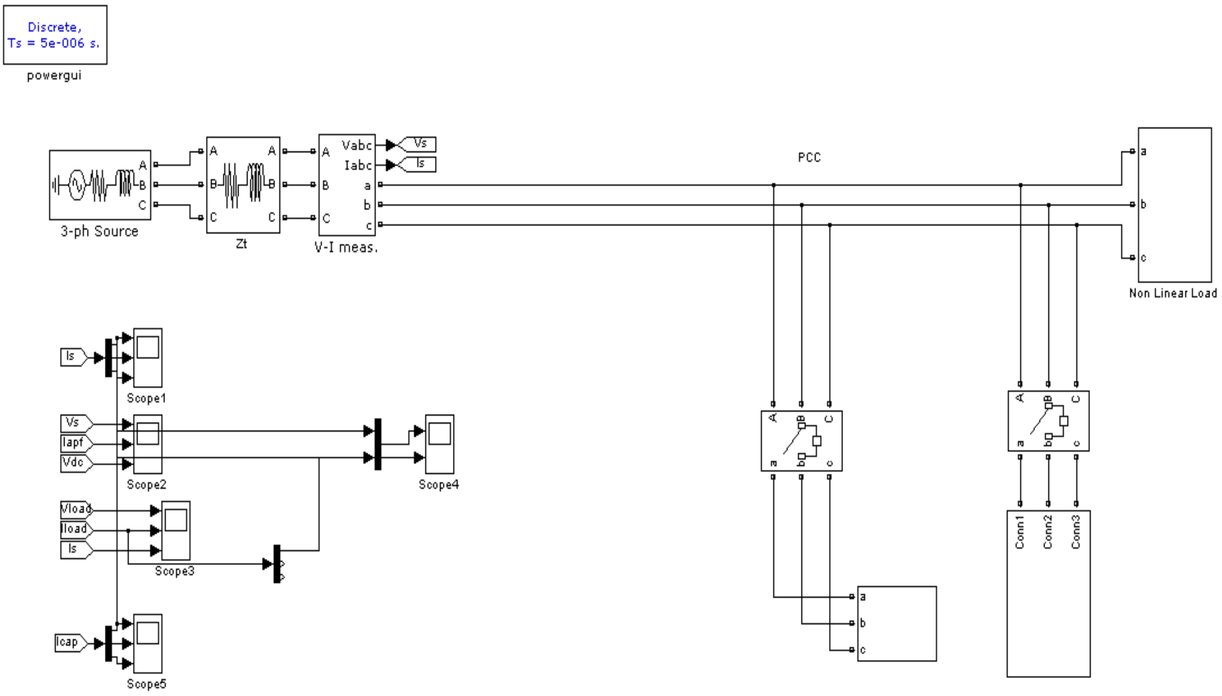

Fig. 4 SIMULINK Model of AFC and Hysteresis Controller based PEH