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Novel Design of a Neuro-Fuzzy (ANFIS) Controller to Improve the Power Dynamics for Minimization of Harmonics Using a Hybrid Scheme

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ABSTRACT: In the research work done in this paper, a hybrid power filter bank (3-ϕ) is proposed for the harmonic elimination in power electronic systems by using a parallel combination of a capacitive filter with a shunt active filter, which is controlled by an ANFIS controller (neuro-fuzzy controller), thus compensating for the voltage / current harmonics in a 3-ϕ 3-wire system fed to an inductive load. Simulations are performed in the Matlab-Simulink environment& the simulation results are obtained. The results shows the efficacy of the method developed for harmonic suppression.

KEYWORDS: Elimination, Breakers, Current, Voltage, Control, Simulation, T H D, Power semiconductor devices, Suppression, Power Quality, Harmonics, Distortion.

I.INTRODUCTION

Our innovative world has turned out to be profoundly reliant upon the ceaseless accessibility of electrical force/energy. Business control, i.e., power available commercially is truly empowering the today's current world to work at its bustling pace. Modern innovation has come too profoundly into our homes and professions, and with the coming of e-trade & commerce is constantly changing the way we interface with whatever is left of world. Electric vitality is a fundamental element for the modern and all-round advancement of any nation. The ideal use of this type of vitality/power can be guaranteed by a quality force/energy/power. The circumstance with power is comparative, the unwavering quality of the supply must be known and the flexibility of the procedure to varieties must be caught on immediately [1]-[10].

As a general rule, obviously, power is altogether different from some other item - it is created a long way from the purpose of utilization and is nourished to the framework together with the yield of numerous different generators and lands at the purpose of utilization through a few transformers and numerous kilometers of overhead and conceivably underground cables. Where the electrical business factories has been privatized, these system resources will be possessed, overseen and kept up by various distinctive associations or companies. Guaranteeing the nature of conveyed force/power at the purpose of utilization is no simple task undertaking and it is extremely unlikely that sub-standard power can be pulled back from the store network or rejected by the client/end-utilizer [11]-[20].

Electrical vitality/power is a key element for the modern and all-round advancement of any nation as currently without electricity, the whole world will be in dark & the country's economy falls down drastically as every working device in the universe requires electricity. Hat's off to Thomas Alva Edison, Benjamin Franklin, who invented this great wonder, which is of great importance today. The ideal usage of this type of vitality/energy can be guaranteed by a quality electrical power with no intrusion. The circumstance with power is comparative, the unwavering quality of the supply must be known and the versatility of the procedure to varieties must be caught on [1] – [99].

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Harmonic spikes have various undesirable consequences for the appropriation framework of the electrical distribution networks. 2 types are there, viz., : short & long term effects. Short impacts are generally the most recognizable and are identified with over the top over voltage mutilation. Then again, long haul (term) impacts frequently go undetected and are normally identified with expanded resistive loss or voltage stress likewise, the consonant streams created by non-straight loads can associate antagonistically with an extensive variety of influence framework gear (electrical power equipments), most strikingly capacitors, transformers, and engines, generators, bringing on extra loss, overheating, and over-burdening.

Interference with telephone cables, lines will be caused by the development of these harmonic currents. In light of the antagonistic impacts that these harmonic surges have on P Q, standards have been created to characterize a sensible structure for control of harmonic surges. Its goal is to guarantee consistent state harmonic limits that are worthy considered by both electric utilities and their clients. [21]-[30].

Distortion of harmonics in power/force appropriation system can be stifled utilizing 2 methodologies in particular, latent/passive and dynamic/active fueling. The passive type of sifting/filter is the least difficult traditional answer for alleviate the mutation in harmonics. Even basically, the utilization of detached components does not generally react accurately to the progression of the electrical energy transmission frameworks. Throughout the years, these detached passive channels have created to the abnormal state of modernity. Some even tuned to sidestep or bypass the particular consonant frequencies" [31] - [40].

Harmonics are *v* and *i* frequency components which are embedded on the crest level of the normal sine *v*&*i*. The symphonious distortion in waveform issues are for the most part because of the significant increment of non-straight loads because of innovative advances, for example, the utilization of force electronic circuits and gadgets, in air conditioning/dc transmission connections, or burdens in the control of force frameworks utilizing power electronic or microchip controllers. Harmonic sources are categorized into 3 types of loads, viz., [41]-[50]:

- House-hold load
- Industry load
- Controlling device

Any power circulation circuit serving present day electronic gadgets will possess some level of symphonious frequencies. The surge *v*&*i* don't generally bring about issues, yet the more prominent the electrical energy or power is drawn by these advanced gadgets or other non-straight loads, the more prominent is the level of voltage mutilation. There are a number of problems which are related to the harmonic generation, they include the following [51]-[60] :

- Equipment mal-functioning.
- Sudden tripping of the breakers.
- Sudden on & off of the lights.
- Large neutral *i*.
- Conductors in the phase, loads, transformer getting heated,
- U P S suddenly getting failed,
- Transformer suddenly getting failed,
- less power factor.
- Voltage & current surges
- Capacity of the system getting reduced [61]-[70].

How to prevent the harmonics ? The efficient method is to choose a device and have good installation practice which will definitely reduce the overall harmonic contents in the device or circuit or equipment or in a part of the network. On the off chance that the issues can't be illuminated by these basic measures, there are 2 fundamental decisions, viz., to fortify the dissemination framework to withstand *v* or *i* surges or to introduce the gadget to constrict or evacuate the harmonics. Procedures for lessening *v* or *i* surges, from shabby to more costly, incorporate latent symphonious channels, confinement transformers, consonant moderating transformers, the Harmonic Suppression Network (HSN) and dynamic channel filtering mechanisms [71]-[80].

The harmonic effect in the system's *v* or *i* is always decided in terms of the T H D, factor, high & low level harmonic contents. In general, any industry application ask for the load v & I be free of harmonics or at the most < 5 % of harmonics. Majority of the literatures after going through them shows that a number of methodologies have been found out to lessen the T H D [81]-[90].

There are assortments of building arrangements accessible to dispose of or diminish the impact of supply quality issues and it is exceptionally dynamic zone of advancement and improvement. In that capacity, clients should know

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about scope of arrangements accessible and the relative merits and expenses. A portion of the vital techniques to minimize sounds/surges in *v*&*i*'s are [91]-[99]

- filter which is passive in nature,
- filter which is active nature,
- separation transformer,
- surge reducing transformer,
- surge suppression system, etc…

The flow of the research work is developed one after another as shown below. A background introduction w.r.t. the work done in this paper was presented in the introductory section in sec. 1. Review about the work done is presented in section 2, which is followed by basic operating principle & design of the ANFIS controller schemein section 3. Section 4 gives the methodology & functional process of each of the ANN scheme. The development of the Simulink model for harmonic elimination in Matlab environment is presented in section 5 followed by the simulation parameters in section 6. The running of the developed simulink models, observation of the results is presented in section 7. Comments on the reduction of THD using the proposed scheme is discussed in section 8. The sec. 9 concludes the work. This is followed by a number of references used in the development of this paper and the author biographies.

II. REVIEW OF THE WORK DONE

All the concepts of Artificial Neural Networks (ANN) has been used in the development of the harmonic elimination system in this section. In this method of harmonic elimination scheme, the ANFIS controlled filter is modeled in MATLAB / Simulink environment. In short to say, *p-q* theory is used with the inclusion of ANN based filter for reference current generation and FL controller for DC voltage control. The number of epochs is chosen in such a way that the amplitude of the harmonics is limited and do not exceed the set IEEE standards.

Capacitor type filter is a HP (High Pass) filter and is used so that it reduces the component rating for the active filter, thus surpassing the overall filter resonance. The shunt filter is being designed as a 3ϕ VSI consisting of 6 control switches. Filter's AC side is being designed in such a way that it is in parallel with the load non-linear as it is a well-known fact that because of the non-linearity of the loads, only the harmonics takes place due to its switching phenomenon. DC-link capacitor is connected to the DC side.

The shunt active filter is designed in such a way that it will compensate, especially the lower order harmonics. The main advantage of using this hybrid combination is the elimination of lower order harmonics clubbed with reactive power compensation in power systems that too for non-linear unbalanced loads. Simulation has been carried out in Matlab and the results meet the IEEE-519 standard recommendations on harmonic levels. From the simulation results, it is observed that this proposed approach gives an excellent THD value compared to other approaches.

The duo combination scheme has got a better harmonic compensation scheme. The proposed system thus estimates the harmonic content present in the source current, which is produced by the non-linear load, which will generate reference waveforms for the VSI, eliminate the harmonic contents and improves the power quality at the source end, thus improves the power filter dynamics to minimize the harmonic levels for a wide range of I_L variations under various operating conditions. At the same time, maintains the compensated line currents balanced, irrespective of unbalancing in the source voltages and deviation in the capacitor voltages due to switching phenomenon, which is seen from results.

III. BASIC OPERATING PRINCIPLE & DESIGN OF THE ANFIS CONTROLLER SCHEME

The basic principle of the ANFIS method is the use of the ***network neurons*** to optimize the ***membership's functions*** of the ***fuzzy controller*** in other words ; an ANFIS is one optimized fuzzy inference system (FIS).

In the Neuro-Fuzzy controller, the simplicity of a fuzzy controller is combined with the intelligent and adaptive nature of the Neuron Network optimization so that the effectivity of control scheme is felt because of the training process involved. The ANFIS controller is developed as per the block diagram shown in the figure with 2 inputs, viz., the error, $e(k)$ and the change in error $\Delta e(k)$ is modelled as follows…..

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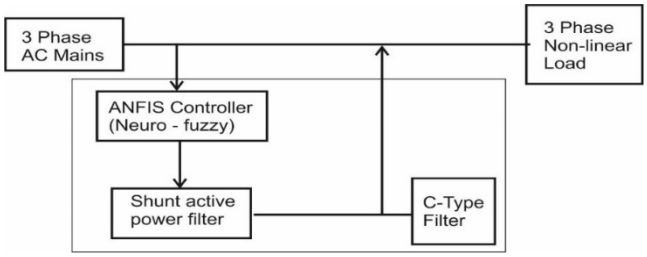

Fig. 1 : Block-diagram of the neuro-fuzzy inference scheme to suppress the harmonic contents in the supply voltage and to improve the power quality

$$e(k) = e_{ref} - e_f$$

$$\Delta e(k) = e(k) - e(k-1)$$

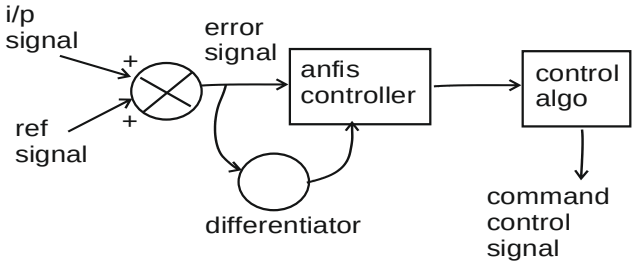

Fig. 2 : Illustration of a typical ANFIS Controller with 2 Inputs

IV. METHODOLOGY & FUNCTIONAL PROCESS OF EACH OF THE ANN SCHEME

There are various functional process of operation of the ANN schme for harmonic suppression in electrical power systems, one by one is described as below ….

A. FUZZIFICATION

The fuzzification is the process of converting the crisp-set into linguistic fuzzy sets using fuzzy membership function. The concept of linguistic variable was introduced to process the natural language. The membership function is a curvature that describes each point of membership value in the input space. Variables are assigned as Negative Big ( ), Negative Medium ( ) Negative Small ( ) Zero, Positive Small ( ), Positive Medium ( ), and Positive Big ( ). The inputs of fuzzification are the error and change in error. The value of input error E (k) and change in error CE (k) are normalized by an input scaling factor. The input scaling factor has been designed such that input values are between -0.032 and 0.032. Membership function has many structures; among those triangular memberships function is used shown in figure because for any particular input there is only one dominant fuzzy subset. Fuzzy rule base is the basic function of fuzzification. A collection of rules referring to a particular system is known as fuzzy rule base. Fuzzy rule base for these seven linguistic variables is shown in table below [86]. Before optimizing fuzzy logic, rules and membership function have to be defined. In our case a '*pats.fis*' named fuzzy logic structure is designed in MATLAB whose decision table is shown in the rule table below.

B. INFERENCE ENGINE

Fuzzy inference engine is an operating methodthat formulates a logical decision based on thefuzzy rule setting and transforms the fuzzy rule base into fuzzy linguistic output. Fuzzy linguistic descriptions are formal representations of systems made through fuzzy IF-THEN rules. They encode knowledge about a system instatements of the form: IF (a set of conditions)are satisfied THEN (a set of consequents) can beinferred. There are several methods for this such as Max-Min method, Max-Dot method. Inference engine is otherwise called as decision making logic, i.e., DML [86].

C. DE-FUZZIFICATION

The last step in the FLC process is the de-fuzzification. These will have a number of rules that transform a number of variables into a fuzzy result, that is, the result is described in-terms of membership functions in fuzzy sets. Several methods are available for de-fuzzification such ascentroid method, centre of sums, and mean of maxima. The Centre of

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Gravity (COG) de-fuzzification method is used. Centre of gravity method is otherwise called as Centroid method, Centre of area method [86].

D. TRAINING THE DATA SETS

The data sets that are required for training purposes are obtained using a PID controller. The given inputs are being converted into linguistic variables. In our case, the fuzzy membership functions, viz., negative big, negative small, zero, positive small and positive big are being used in the design. The elements of this rule base table are determined based on the theory that in the transient state, large errors need coarse control, which requires coarse input / output variables; in the steady state, small errors need fine control, which requires fine input/output variables [86].

E. RULE TABLE

Based on this the elements of the rule table is obtained and used in the controller design. The membership functions used for the inputs before and after training are also seen below using a rule based design done in the artificial neural network scenario as below. It is observed from the output waveforms seen from the scope of the simulink model after it being run for a certain amount of time, that smooth waveform is being obtained, which is free of harmonics. In our case, upto 7th harmonic is being removed using the ANFIS design. All the parameters used in this table are further used for the generation of the membership function which can be developed in Matlab.

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

Table 1 : Table showing the fuzzy logic rules membership function compiled in the form of a table

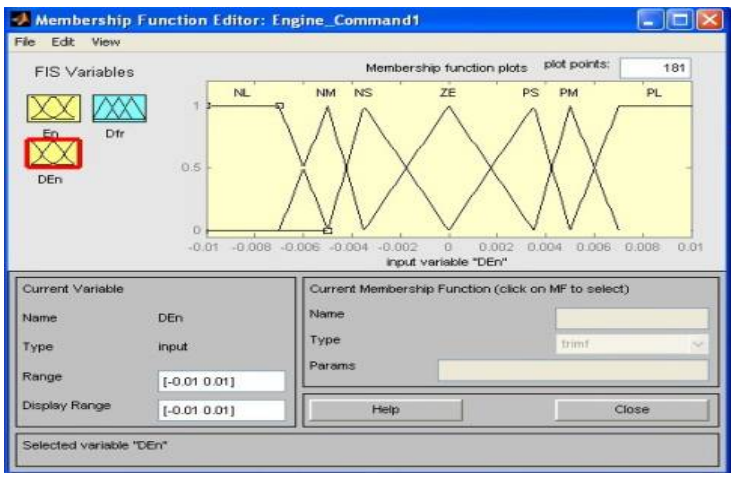

Fig. 3 : Fuzzy membership functions developed in Matlab

V. DEVELOPMENT OF THE SIMULINK MODEL

The simulink model is constructed using thyristors bridges, DC sources, transformers, inductive loads, gain blocks, multiplexers, FWDs, scopes, sinks, output sources, comparators, pulse generators and the connectors. All these mentioned blocks are available in the simulink modelling library. All the blocks have to be pulled from the simulink library into the model and has to be built, the file being named as *.mdl. Apart from these, various tool-boxes such as

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control system tool box, sim-power-systems tool box, signal processing tool boxes available in the simulink library is being used.

Scopes are connected at the o/p &i/p's to observe the different waveforms. The simulink diagram for the harmonic suppression developed in the Matlab environment is shown in the figure below, wherein 4 thyristorized bridges are being used for the waveform generation, the ANFIS controller is used for the training purposes and to suppress the harmonics present in the AC supply fed to the load.

The input to the neuro-fuzzy harmonic elimination scheme is the AC voltage source, which is given as input to the thyristor bridge circuit. A pulse generator is used to trigger the thyristors in the bridge circuit. The output of the bridge circuit is connected to the R-L inductive load through the ANFIS controller. The training process algorithms are put inside the ANFIS controller. The scopes are connected at the output points to see the voltage & current waveforms.

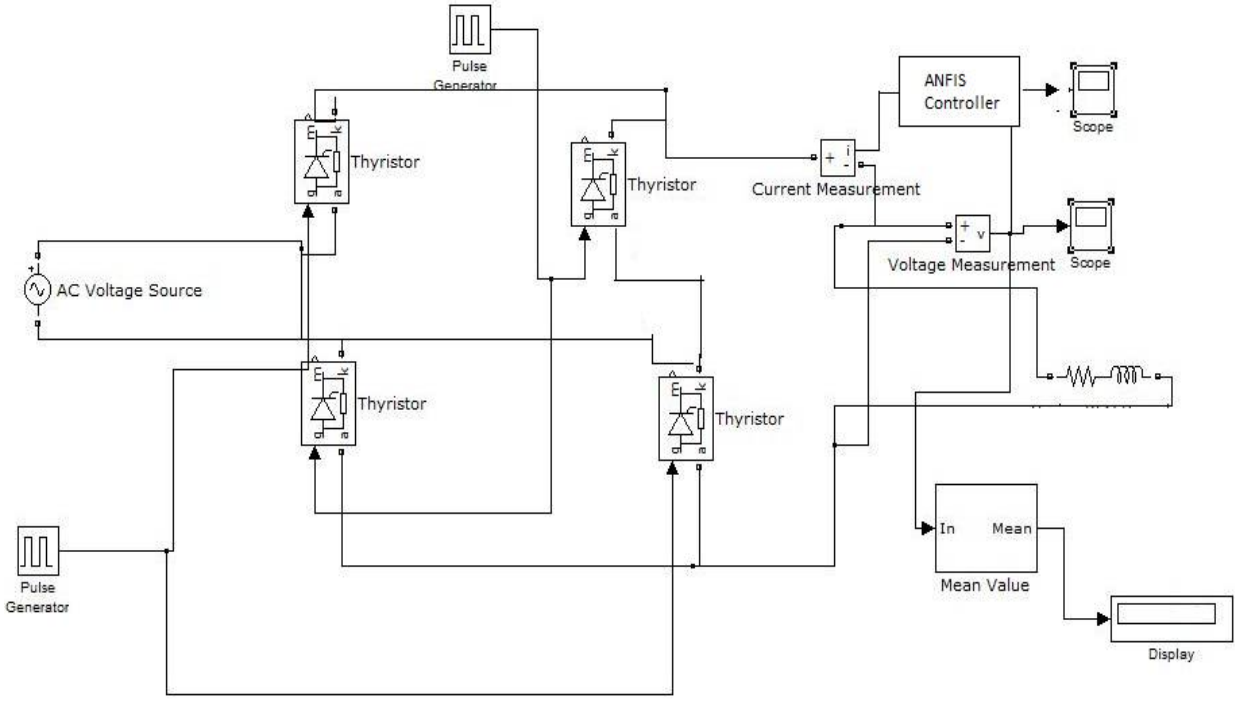

Fig. 4 : Developed simulink model for ANFIS controller for harmonic eliminations

VI. SIMULATION PARAMETERS SELECTION

Various parameters are to be set in the different blocks that are used in the development of the simulink model before running the developed Simulink model, which are shown in the below figures respectively. Once the block is being selected, it is being double clicked & the simulation parameters are entered into it and saved.

VII. RUNNING OF THE DEVELOPED SIMULINK MODELS, OBSERVATION OF THE RESULTS

The developed simulink model is run for the requisite simulation time, 2 waveforms are observed, before & after the incorporation of the fuzzy controller. From the simulation results, it can be seen that the difference between before and after the incorporation of the ANFIS scheme, the harmonics are removed to a greater extent. This shows the effectiveness of the method demonstrated in this section as to how to improve the power quality and obtain smoothened outputs at the receiving ends.

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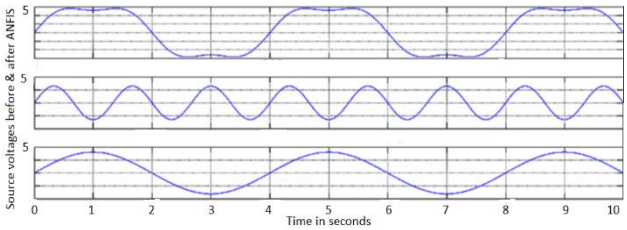

Fig. 5 : Simulation output for the plot of load voltage before and after the incorporation of the ANFIS (artificial neural network's neuro-fuzzy) controller …. before, imbalance seen due to switching, after the incorporation of the ANFIS controller, balance is seen

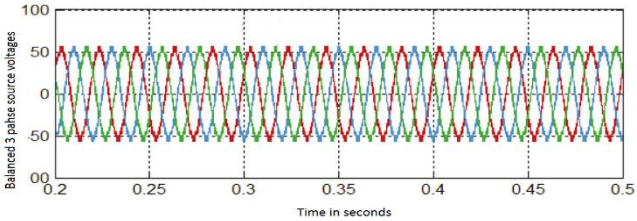

Fig. 6 : Matlab output of balanced 3-phase source voltages after incorporation of ANFIS (Artificial Neural Network's Neuro-Fuzzy) controller

The results of the ANFIS controller show the effectiveness of the method developed. The plot of one phase voltage of the supply before and after the incorporation of the ANFIS (Artificial Neural Network's Neuro-Fuzzy) controller is shown in the figure above. It is seen that before the application of the controller, imbalance was seen due to switching, after the application of the ANFIS controller, balance could be seen in all the wavefomrs and the harmonics are removed to a greater extent.

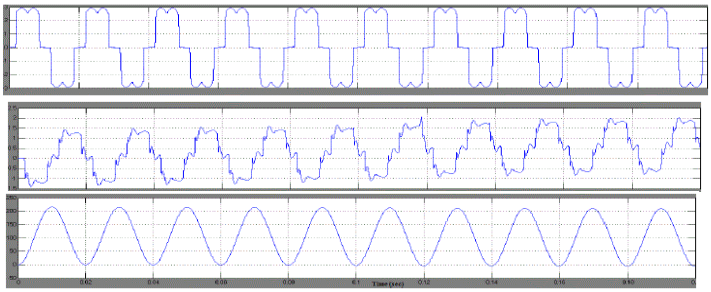

Fig. 7 : Plot of load current before and after the incorporation of the ANFIS (Artificial Neural Network's Neuro-Fuzzy) controller …. before, imbalance seen due to switching, after ANFIS controller, balance seen

VIII. COMMENTS ON THE REDUCTION OF THD USING THE PROPOSED SCHEME

The total harmonic distortion for the output waveforms was calculated using the THD formulas for the current and voltage and the results were tabulated neatly in the form of a THD reduction table given above. From these quantitative results, it can be inferred that using a selective harmonic elimination scheme, i.e., eliminating a particular harmonics, the technique has worked successfully as before the introduction of the harmonic filter, the THD was 0.5717 and after the introduction of the filter, the THD was 0.0078, i.e., there is a substantial reduction in the harmonic contents of the load current (from 57.17 % to 0.78 %).

Similarly, the THD was 0.8231 before the introduction of the filter and after the introduction of the filter, the THD was 0.0136, i.e., there is a substantial reduction in the harmonic contents of the load voltage (from 82.31 % to 1.36 %). This can be seen from the Matlab output THD waveform results. The simulation results show the effectiveness of the methodology proposed. The net power factor was improved to 0.97and is found to be best in all cases in our work considered, in the sense that more than 90 % of the harmonic contents are being removed both at the voltage level and at the current level.

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Table 2 : Quantitative results of THD For *V* &*I* waveforms before and after harmonic reduction scheme employed using ANFIS Method (Neuro-Fuzzy Method)

Type of harmonic elimination method	THD Before Harmonic Suppression (load *v*)	THD After Harmonic Suppression (load *v*)	THD Before Harmonic Suppression (load *i*)	THD After Harmonic Suppression (load *i*)	Power Factor	Remarks
ANFIS ANN Neuro fuzzy	0.8231 82.31 %	0.0136 1.36 %	0.5717 57.17 %	0.0078 0.78%	0.97	I - the Best

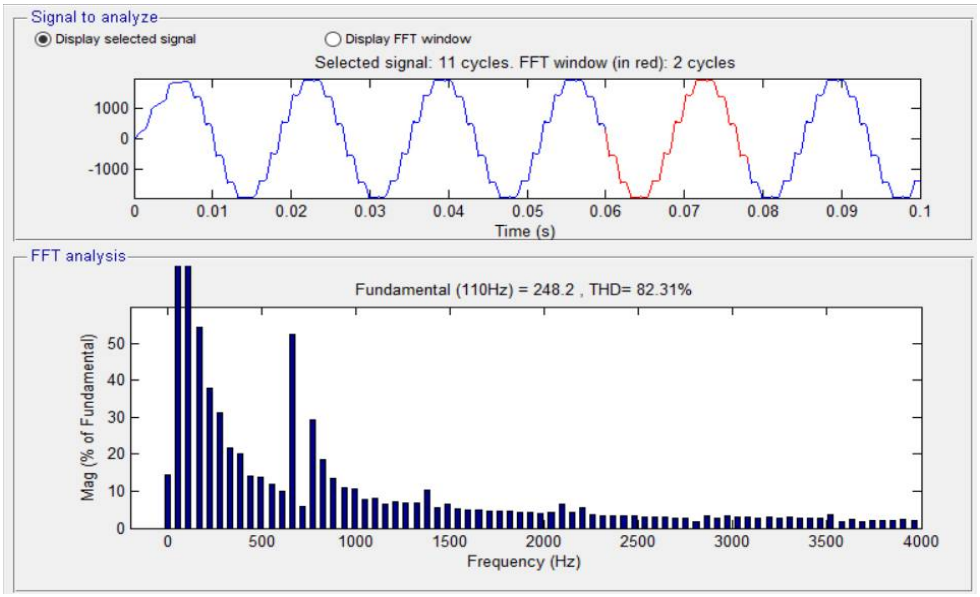

Fig. 8 : Waveform Showing the THD before Applying Compensation Using ANFIS (V)

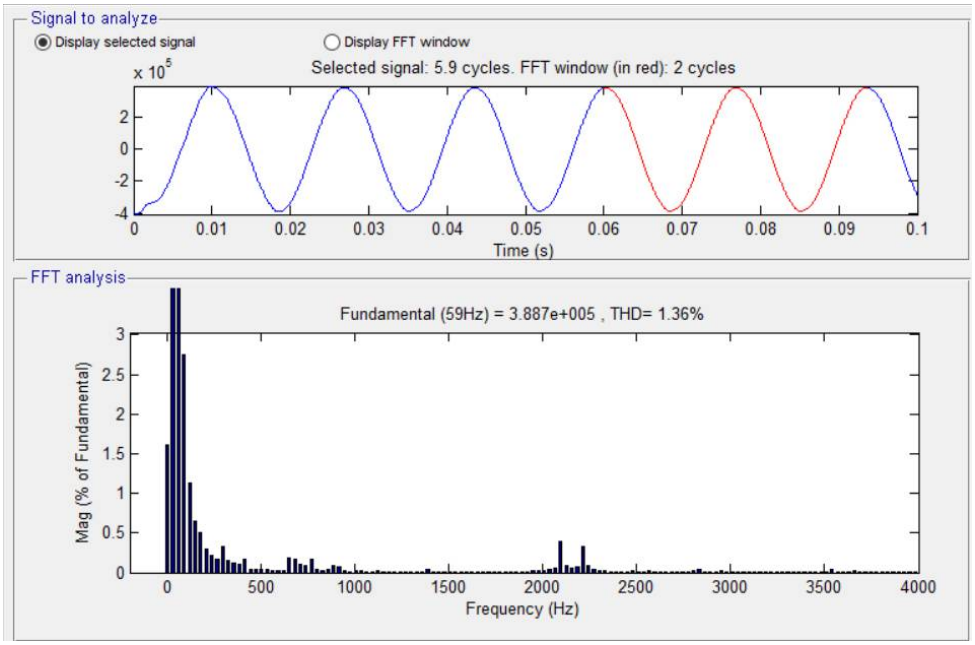

Fig. 9 : Waveform Showing the THD after Applying Compensation Using ANFIS (V)

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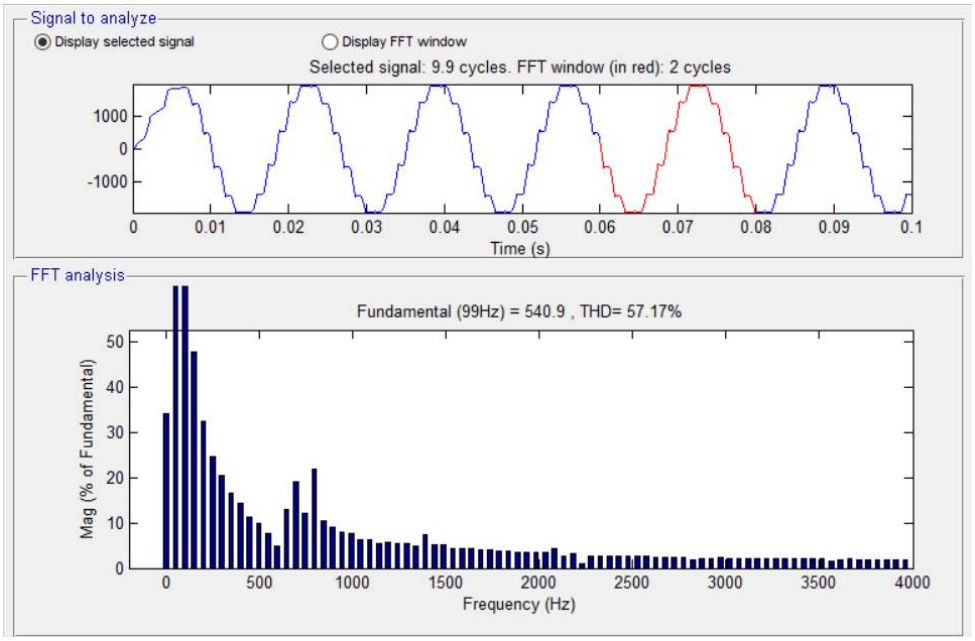

Fig. 10 : Waveform Showing the THD Before Applying Compensation Using ANFIS (I)

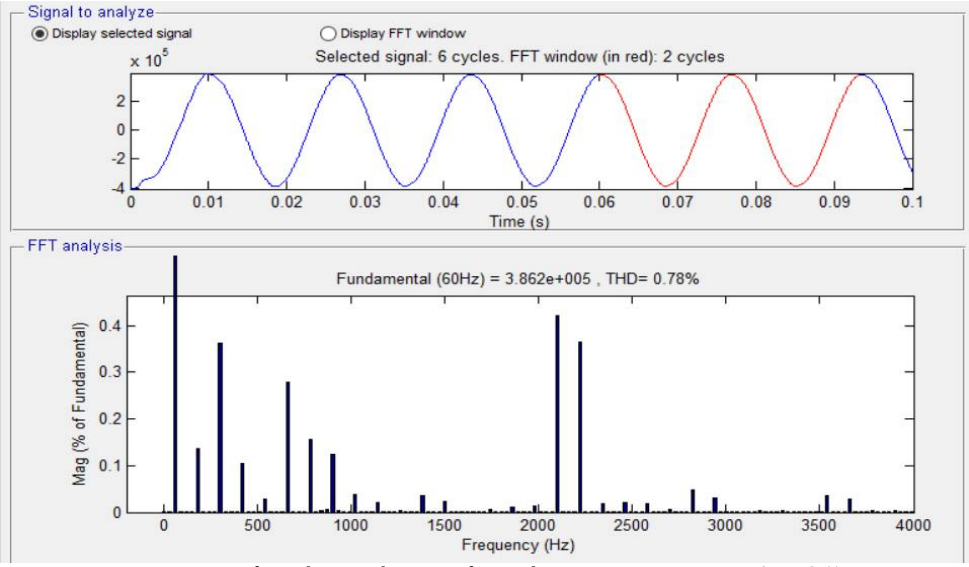

Fig. 11 : Waveform showing the THD after applying compensation using ANFIS (i)

IX. CONCLUSIONS

Research was done w.r.t. analysis of the surge-harmonic effects on the system components & its effectiveness was studied in greater depth resulting in a number of contributions towards the same during the switching on/off of the device process. The early location, concealment of sounds in electrical, electronic, PC, instrumentation, mech. and aviation framework systems is an essential parameter which must be considered w.r.t. the wellbeing, unwavering quality, effective operation of a wide range of system frameworks which are working on power and must be handled genuinely & intelligently. Extensive literature survey was being carried out in this exciting field.In this context, Novel design of a neuro-fuzzy (ANFIS) controller to improve the power dynamics for minimization of harmonics using a hybrid scheme was presented in this paper & was exclusively demonstrated by Matlab-Simulink environments and hence the results show the effectiveness of the method adopted.

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BIOGRAPHY

Dr. M.S. Nagaraj was born in Karnataka, India. He did his graduation from the prestigious Govt. BDT College of Engg., Davanagere, which was affiliated to Mysore University in Electrical & Electronics Engg. Branch in the year 1986. Further, he did his post-graduation, M.Tech. (Power Systems) in the year 1990 from the prestigious National Institute of Engg., Mysore, which was affiliated to the Mysore University. Finally, he completed his Doctoral Degree, i.e., Ph.D. in Electrical & Electronics Engg., from the Visvesvaraya Technological University (VTU) in the year 2008. He worked as a Lecturer in EEE Dept. of STJIT, Ranebennur from 1986 to 1991. Then, he worked as a Lecturer at BIET, Davanagere from 1991 to 1997 & later on promoted to the level of Senior Lecturer from 1998 to 2007 and again promoted to the level of Assistant Professor from August 2007 to July 2008. After his completion of Ph.D. from VTU, he was promoted as Professor from September 2008 in the department of E & E and currently, he is working as Professor and Head in the department of E & E @ Bapuji Inst. of Engg. & Tech., Davanagere, Karnataka, India. He also took initiative of the Electrical Maintenance in BIET Campus. He was awarded as a best teacher for several times from the college for achieving 100% result in the subjects handled many times. He is a life member of the ISTE & Institution of Engineers. He has taught a number of subjects such as Basic Electrical Engineering, Network Analysis, Control Systems, Field Theory Power Electronics, Signals & Systems, Digital Signal Processing, Power system Analysis, Artificial Neural Network, Computer Application to Power Systems, Power System Operation & Control. He has published more than 40 papers in various journals & conferences. He has attended a number of conferences, seminars, guest lectures, FDPs, symposiums, training programs, workshops, etc..& also conducted many such programs in the places where he has worked so far. He worked as a Member of BOS & BOE of Kuvempu University, Davangere University & VTU. His areas of interests are Power electronics, Power systems, Renewable energy, Control of electrical apparatus, Power system operation & control, etc…

Dr. P.S. Venkataramu was born on 12th December. He did his graduation from the prestigious Visvesvaraya Technological University (VTU) in Karnataka. Later on, he worked for 14 years from 1983 to 1997 as an electrical engineer in the Govt. of Goa. Then, he served as the Dean in the prestigious Vellore Inst. of Technology in Vellore, Tamil Nadu for a period of 10 years from 1997 to 2007. Then, he took the position of Principal in Gyan Ganga Institute of Technology & Management, Bhopal, Madhya Pradesh and worked there for a period of nearly 8 years from 2007 to 2015. Currently, he is the Director-Internal Quality at Reva University since 2015. An Electrical Engineer after 15 years of Service involved in many power projects from Conception stage to Commissioning stage at Goa, driven by the passion towards Teaching became an Engineering Teacher, worked in various capacities from Assistant Professor to Dean At V.I.T. University, Vellore for 10 years. He has got a passion to build and nurture a new engineering Institute drove to Bhopal as a Founder Principal of GyanGnaga Institute of Technology & Management and did excellent job there. This long journey of 15 years in Industry as an engineer and 18 years as an engineering Teacher and an academic Administrator taught him the skill of developing &Enhancing the overall quality of Education in general and engineering Education in particular and hence taken up an assignment as the Director-Internal Quality at REVA University a newly born University at Bengaluru. He has attended a number of conferences, seminars, guest lectures, FDPs, symposiums, training programs, workshops, etc..& also conducted many such programs in the places where he has worked so far. His areas of interests are Power electronics, Power systems, Renewable energy, Control of electrical apparatus, etc…

Mr. Rajesh Maharudra Patil was born in Karnataka, India. He did his studies from the prestigious Visvesvaraya Technological University, Karnataka. He is pursuing his Ph.D. programme in Electrical & Electronics Engg. From the prestigious Visvesvaraya Technological University (VTU) as a part-time research scholar & working on the reduction of harmonics in power systems to improve the power quality. He is also working as an Assistant Professor & Head of the Department of Electrical & Electronics Engg. @ Balekundri Institute of Technology, Belagavi, Karnataka since a very long time. He has published a number of papers in various national and international journals & conferences. He has attended a number of conferences, seminars, guest lectures, FDPs, symposiums, training programs, workshops, etc..& also conducted many such programs in the places where he has worked so far. His areas of interests are Power electronics, Power systems, Renewable energy, Control of electrical apparatus, Power system operation & control, etc…