Novel Repetitive Control Technique for Three Phase Four Wire Shunt Active Power Filter

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Abstract- **Within the scope of this paper is an illustration of a discrete repeating control mechanism for a three phase, four wire (3P4W) shunt active power filter (SAPF). In power electronics device control designs, it is common practice to make use of two control loops: one with a quick acting inner current control loop and another with a slow acting outside voltage loop. The PI regulator has a hard time keeping track of the reference for the inner current loop since it is periodic. The ability of the repetitive controllers, sometimes known as RC, to follow periodic signals is well known and has earned them widespread recognition. RCs provide great gain at all frequencies. The significant increase in the higher frequency band may contribute to instability. As a direct consequence of this, the sensitivity function of the regular RC will be squared in the research that is being suggested. For the purpose of enhancing the power supply's overall quality, this project makes use of a fuzzy logic controller. This technique results in a sensitivity function that has a moderate amplitude, and it provides significant notches at frequencies ranging from low to middle, while it creates less notches at higher frequencies. This control approach has been evaluated on the 3P4W SAPF, and it is now being implemented there.**

Index Terms—Repetitive Control, Active Power filter, harmonic compensation, Power Quality, 3P4W, Load Compensation, Non-linear load, Unbalanced Load, Fuzzy logic controller.

I. INTRODUCTION

There are a variety of difficulties at the distribution level of the power system network, the bulk of them are linked to load imbalance, reactive power, current harmonics, and other comparable problems. In order to ensure that the generating and transmission operations continue unabated, it is crucial that problems of this sort be handled at the distribution level in and of themselves, from the perspective of the operator of the power system. In the past, problems with the quality of the power supply were fixed by using electromechanical devices such as tap-changing transformers, passive filters, and synchronous condensers. There are still issues even though a variety of specialist power devices, including as dynamic voltage restorers (DVR), active power filters (APF), static compensators (STATCOM), and unified power quality controllers (UPQC), are now often used to handle power quality issues. Depending on the situation, a voltage or current regulated voltage source inverter is typically used as either a series or shunt coupled device. When the SAPF can be controlled to supply load current harmonics, imbalance, and reactive current demand in a way that ensures grid side current always maintains a balanced set of sinusoidal current at unity power factor (UPF), this strategy is advised for usage.

Creating a quick-response controller is a common challenge in the field of controller design since the SAPF is a current-controlled device and the inner current control loops are substantially faster than the exterior sluggish voltage loops. The periodic nature of the inner current signals must also be transformed into corresponding DC signals in order to regulate them using a straightforward PI controller. This is required to regulate the signals generated by the internal current. Because of this, the precision of the transformation—which is particularly susceptible to variations in frequency and phase angle—determines how successful the controller is. The SAPF's inner current loop has previously been the subject of several alternative control methods. The principal controllers used by the great majority of them are passivity-based control (PBC), proportional resonant control (PR), hysteresis control, and deadbeat control (DB). In this instance, the PR can only be set for certain harmonics, the PBC and DB require a precise model of the system, and control performance may worsen due to parameter variations. The hysteresis controller's variable switching frequency may also cause resonance issues. The PI is the simplest to comprehend, however it cannot be used with oscillating signals. Additionally, reports of other artificial intelligence-based control strategies have been made. These kinds of approaches have two main problems: they have a severe shortage of training data for offline tuning, and they have a considerable increase in processing overhead for online adaptive tuning. Use of repetitive controllers (RC) is advantageous since most power electronics converters deal with periodic signals and the controller may access past data about the input signal.

The design of RC is based on internal model principle theory (IMPT), which may be used to attain zero steady-state error while tracking different frequency harmonic components. Since IMPT can be utilized to provide zero steady-state error, it can be used to construct RC. Given this situation, paying close attention to the harmonic frequencies will be beneficial in a big way. As a result, when SAPF is well controlled, RC shows a high level of efficacy in eliminating harmonics. A conventional digital RC can be created by adding n delays, which is what most people do. The letter n is used to represent the integer number of samples that make up the input signal's basic cycle in this context. Building a robust RC may be difficult since any arithmetic error or poor modeling might push the controller into an unstable area. Additionally, if the signal frequency—in this case, the frequency of the grid voltage—changes, the performance of straightforward RC controls may be adversely impacted. Due to the tuning of the RC, which cancels out unwanted harmonics that are integer multiples of the fundamental frequency, frequency changes have the potential to render the SAPF unusable. The variable sample rate approach for RC design has been proposed as a potential remedy for this issue. This method attempts to correctly reject harmonics. A method somewhat similar to this one that employs a FIR filter based on Lagrange interpolation is presented to imitate the fractional component of n. On the other hand, the fractional delay and shifting sample rates indicate significant changes in system dynamics and call for various mathematical operations, respectively. Similar methods based on cycle sampling techniques have been documented. In these procedures, the sample sites are changed to improve stability and correct for fractional order phase leads after each cycle. However, changing the sample point placements may impact the capacity to track defects in stable states. The Parallel Structure Repetitive Control, or PSRC for short, was developed with the help of several authors. For PWM inverter/converter control, this control approach uses multiple order harmonic internal models. Calculating the gains for numerous parallel loops at once is the most challenging part of PSRC. Additionally, in order to achieve faster convergence, it is necessary to alter each and every harmonic frequency component, which is exceedingly challenging to execute in any real-world situation.

As a result, the main goal of the work that has been presented is to streamline the RC design approach while also stepping up the control efforts. The sensitivity function was altered in accordance with a fundamental methodology described in [29], and as a result, it was taken as the square of the original sensitivity function. To accomplish the targeted goal, this was done. This method creates notches that are deeper and have a larger control range for more fundamental frequencies without placing an undue burden on the user's computational resources. Strong proof that the slight fluctuation in grid frequency has no effect whatsoever on the control's overall efficiency may be seen in the larger notch spectrum. Furthermore, the fact that the sensitivity function is low in amplitude and has deep notches at all integer multiples of the fundamental frequency ensures that unwanted multiple frequency components are removed without phase lag. This is made possible by the function's small amplitude. It has been proven that this strategy is very suitable for the control of APF, whose main purpose is to eliminate undesirable frequencies in order to obtain a lower overall harmonic distortion level. The adoption of such a reliable controller for APF, where it was developed, simulated, and successfully verified by experimental data, was therefore the most significant contribution.

II. SYSTEM MODELLING AND CONTROL

Figure 2.1 presents the comprehensive schematic diagram of the system that was recommended. In this configuration, a four-leg IGBT-based power electronics converter is managed as a shunt active power filter (APF). During the course of a power frequency cycle, the switching period of each IGBT is altered. This is done so that, when viewed from the grid side, the combined effect of an unbalanced nonlinear load and an injected current from the SAPF appears to be a balanced resistive load. This results in a complete and flawless set of balanced resistive load currents that can be extracted from the grid, which makes it possible for a grid with a power factor of one to work It is essential to take into consideration the fact that the neutral load current demand, also known as the imbalance current component, is satisfied by the fourth leg of the SAPF in order to maintain a grid side neutral current that is less than zero. In addition to this, it demonstrates that the grid is functioning in a balanced manner. Consider the following illustration of a non-linear, unbalanced load that draws a complex amount of power:

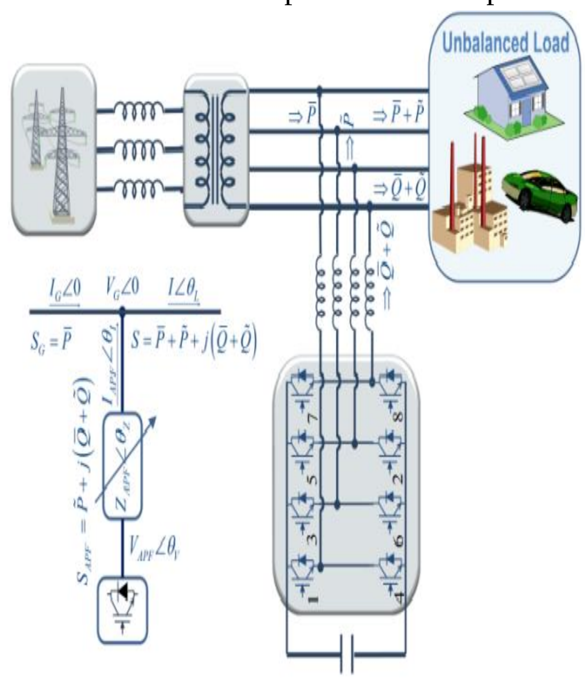


Fig.2.1. Schematic of 3P4W Shunt Active Power Filter

$$S = P + jQ = \bar{P} + \tilde{P} + j\left(\bar{Q} + \tilde{Q}\right)$$

Altering the injected currents may be accomplished by manipulating the SAPF's impedance, phase angle, and terminal voltage respectively. This particular objective may be attained by toggling the switches that control the power electronics in such a way that both the load impedance and the SAPF impedance become pure resistive loads that can be powered by the grid. As a consequence of this, the operational idea of load compensation is shaped by the switching order of several switches inside the SAPF. The functionality of the SAPF may be regulated through the utilization of outer voltage and inner current control loops. When contrasted with the slow-moving dynamics of the voltage control loops, the tremendously rapid dynamics of the current control loops can be seen. The major objective of the voltage control circle is to keep the voltage on the dc-link capacitor at a constant level, which in turn indirectly creates the reference for the active power that the APF requires in order to compensate for the switching losses it incurs. The PI regulator is utilized in order to monitor the difference in voltage that exists between the reference value (Vdc*) and the actual value (Vdc). The output of the PI regulator is what determines the reference for the active current component, which is denoted by id*. Since indirect control mode is being used to regulate the APF, the reactive current component, denoted by iq*, is made to have a value of zero. The phase lock loop's (PLL) grid synchronization angle is used in the calculation of the grid side reference currents (ia*, ib*, and ic*). In order to achieve grid side balanced operation, the neutral reference current, denoted by in*, is made to equal zero. The repeating controller that has been recommended monitors the error currents until they reach a value of zero while simultaneously comparing the actual grid side currents to the reference currents that have been set. Figure 2.2 provides a visual representation of the whole concept as well as an explanation of the controls.

Control Description:

Regulating power electronic converters that are connected to the grid requires the utilization of the rotating-reference frame theory-based abc-dq transformation, which is also referred to as Park's transformation. This particular alteration has the crucial feature of creating quasi-DC signals, which are easy to understand because of their simplicity. Operating a fundamental resistive-inductive load with a straightforward control strategy may be accomplished with the help of a low-bandwidth proportional-integral (PI) controller.

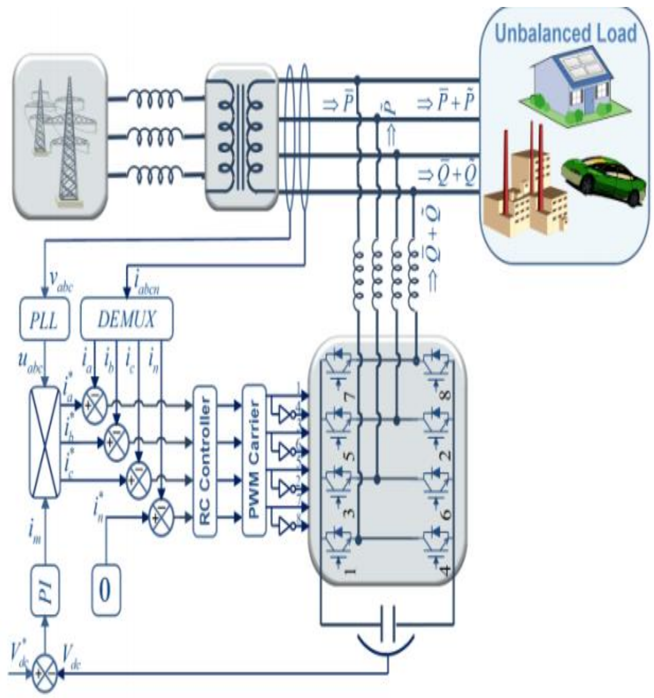


Fig. 2.2. Control Description of 3P4W Shunt Active Power Filter.

III REPETITIVE CONTROLLER DESIGN:

Repetitive controllers are often utilized where there is a requirement to address control challenges brought on by the presence of periodic disturbances or signals that must be regulated at predetermined time intervals. According to the IMPT, a generator that outputs a periodic signal has to be incorporated into the feedback loop of the controller in order for it to be possible to monitor the periodic reference signal. The periodic signal generator makes use of large time delay terms that are a good match for the periods that are present in the reference signal. When the system is used in the real world, a zero-phase FIR low pass filter H(z) is utilized to minimize the gain at those frequencies where the behavior of the system is not clearly characterized. It is essential to be aware that this FIR low pass filter takes on the form of a conventional low pass filter, denoted by the formula q(z, z-1), when the gain of the controller is decreased to levels that are finite for all frequencies. A typical repeating controller with a zero-phase error low pass filter is shown in Figure 2.3.

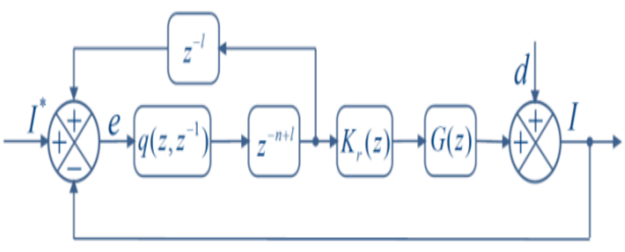


Fig. 2.3. Structure of Typical Repetitive Controller.

Here, the main objective of this particular controller is to achieve smaller magnitude of sensitivity function at the fundamental frequencies.

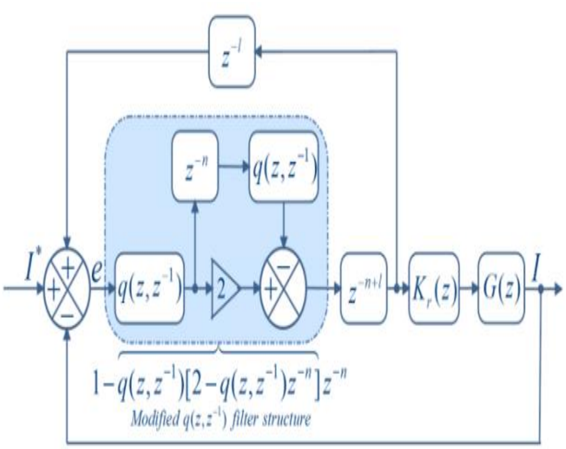


Fig. 2.4 Structure of Modified Repetitive Controller.

IV.FUZZY LOGIC CONTROL

FLC determined by the set of linguistic rules. The mathematical modeling is not required in fuzzy controller due to the conversion of numerical variable into linguistic variables. FLC consists of three part: a. Fuzzification, b. Interference engine, c. Defuzzification. The fuzzy controller is characterized as; For each input and output there are seven fuzzy sets. For simplicity a membership functions is Triangular. Fuzzification is using continuous universe of discourse. Implication is using Mamdani's "min" operator. Defuzzification is using the “centroid" method.

V. Simulation Block Diagram:

The proposed system is simulated using the various modules of MATLAB/Simulink SimPower System tool box. A 4-leg inverter is not readily available in Simulink library. Therefore, the 8 no. of IGBT’s have been taken to form a current controlled voltage source converter, where it is connected in parallel with load to act as SAPF. The driver circuit for individual IGBT is also developed in Simulink itself. The individual switches of SAPF are controlled to obtain the 3-phase balanced set of fundamental grid currents at unity power factor with their respective grid phase voltages despite of highly unbalanced non-linear load connected at point of common coupling (PCC) under varying load conditions. An unbalance 3-phase 4-wire non-linear variable load is simulated using both single phase as well as 3-phase load with rectifier, resistive and inductive load profile.

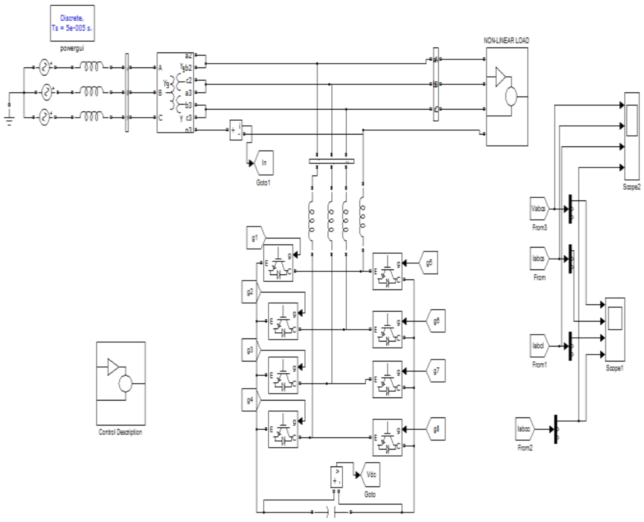
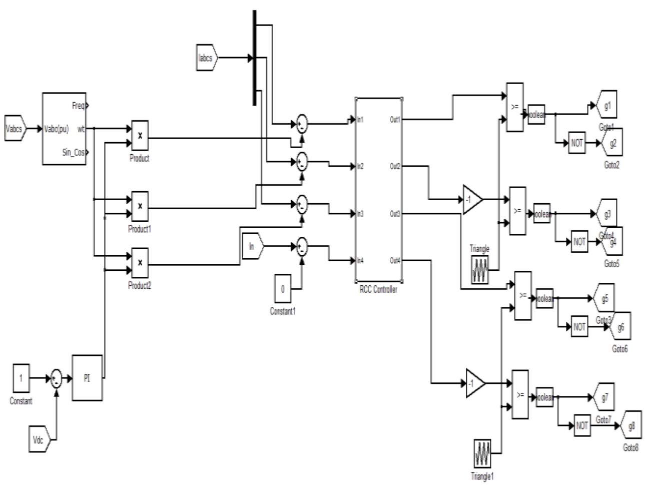


FIG5.1:Simulink Block Diagram



Fi5.2:Control Block Diagram

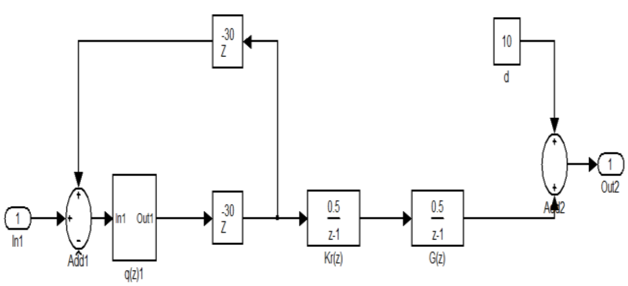


Fig5.3: RC Controller

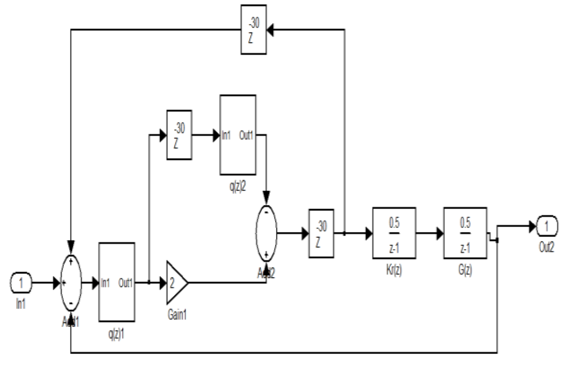


Fig5.4: Modified RC Controller

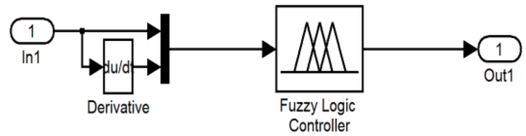


Fig5.5: Fuzzy Logic Controller Controller

Simulation Results:

The simulation results comprising the waveforms of grid side voltage (VG), grid side current (IG), unbalanced load side current (IL) and injected SAPF currents (IAPF) are shown in Fig.. Here, it is worthwhile to mention that the simulation study has been carried out with two different controllers on same system with same parameters for the comparison purpose. The Fig. 5 .6 shows the simulation results with the RC controller as used in our previous work .

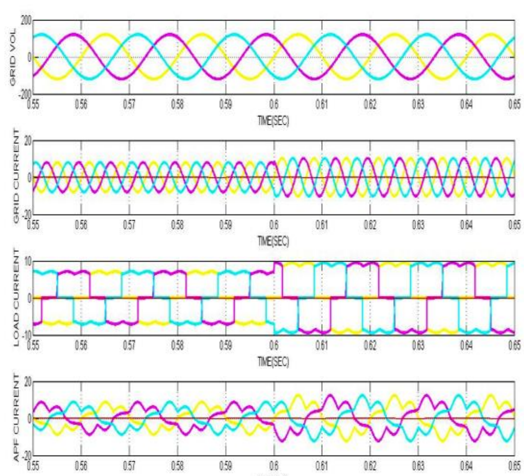


Fig. 4.6 Simulation results with RC: (a) Grid side voltages, (b) Grid side currents, (c) Unbalanced load side currents, (d) APF currents.

This shows the simulation results with proposed RC controller. On carefully analyzing the load current waveforms, it can be observed that initially, a three phase balanced nonlinear rectifier load is connected in the system. At t = 0.6 sec, the non-linear load is suddenly increased by 75% of its initial loading and again at t = 0.8 sec., the load is reduced to its initial value. At t = 1.0 sec, a RL load is connected to the phase A of supply.

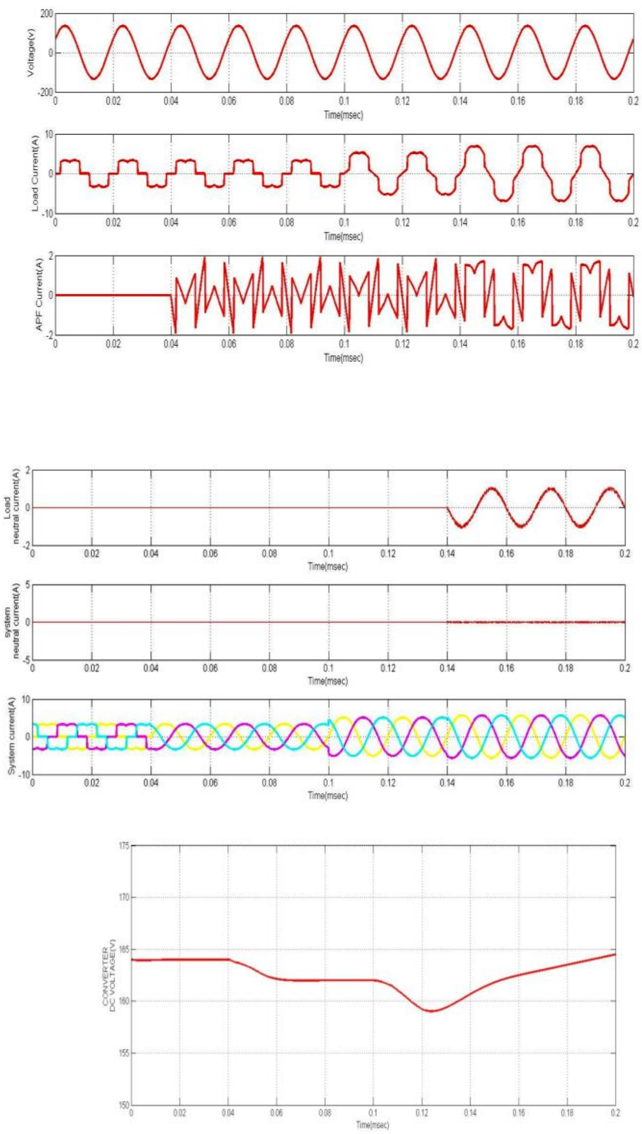


Fig. 5.7. Simulated waveforms of the proposed Fuzzy control scheme. (a) Phase to neutral source voltage. (b) Load Current. (c) Active power filter output current.(d) Load neutral current. (e) System neutral current. (f) System currents. (g) DCvoltage converter.

CONCLUSION

Within the scope of this research, a modified RC controller modeling, design, and simulation have been presented for the purpose of controlling SAPF. From a modeling and design point of view, it has been proved that the modified RC controller offers a broader control bandwidth than the conventional RC controller does. The recommended controller produces satisfactory results when used in conjunction with the dynamic operating conditions. In addition, it has been proved that the SAPF is capable of managing non-linear load demand in settings that are both balanced and imbalanced. The results of many simulations are presented here to provide weight to these claims. The statements have been supported by a significant amount of data obtained through experimentation, which brings us to our final point. You'll notice that in this scenario, the reactive current demand of the load, current harmonics, and current unbalance are all rectified in such a way that the network side currents are continually maintained as a 3-phase balanced set of fundamental current at UPF. This is something that you'll be able to observe for yourself. The load neutral current need is additionally met locally from the fourth leg of the SAPF in order to bring the grid side neutral current down to zero.

REFERENCES

[1] Pablo Acuna, Luis Moran, Marco Rivera, Juan Dixon, and Jos´eRodriguez, “Improved Active Power Filter Performance for Renewable Power Generation Systems,” IEEE Trans. Power Electronics. vol. 29, no. 2, pp. 687–694, Feb. 2014.

[2] M. Aredes, J. Heffner, and K. Heumann, “Three-phase four-wire shuntactive filter control

strategies," IEEE Trans. Power Electron., vol. 12, no. 2, pp. 311–318, Mar. 1997.

[3] H. Akagi, "New trends in active filters for power conditioning," Ind. Appl. IEEE Trans. On, vol. 32, no. 6, pp. 1312–1322, 1996.

[4] C. Lascu, L. Asiminoaei, I. Boldea, I. Boldea and F. Blaabjerg, "High performance current controller for selective harmonic compensation in active power filters," IEEE Trans. Power Electron., vol. 22, no. 5, 1826-1835, Sep. 2007.

[5] Q. N. Trinh and H. H. Lee, "An advanced current control strategy for three-phase shunt active power filters," IEEE Trans. Ind. Electron., vol. 60, no. 12, pp. 5400-5410, Dec. 2014.\

[6] K. R. K. V. Prasad, Ravindra Kollu & Sharad Kumar Tiwari (2023) "An Optimal Multi-Objective Approach for Distributed Generation and AVR Placement in Distribution Networks Using IPMBSA", Electric Power Components and Systems,51:15,1523-1545, DOI: [10.1080/15325008.2023.2199754](https://doi.org/10.1080/15325008.2023.2199754)

[7] Jayaram, K., Ravindra, K., Prasad, K.R.K.V. *et al.* A multi-objective approach for renewable distributed generator unit's placement considering generation and load uncertainties. *Int J Energy Environ Eng* **13**, 995–1019 (2022). https://doi.org/10.1007/s40095-021-00438-5

[8] B. Murali Krishna, V. Sandeep, Narendra B.K., K.R.K.V. Prasad, "Experimental study on self-excited induction generator for small-scale isolated rural electricity applications.", Results in Engineering,18,2023,101182.https://doi.org/10.1016/j.rineng.2023.101182.

[9] K. R. K. V. Prasad, Ravindra Kollu "Optimal Capacitor Placement, AVR Placement and Conductor Selection Along with DG Using BSA", International Journal of Adv Science and Tech,2005-4238.

[10] Prasad, K. R. K. V., et al. "Machine Learning Algorithms Are Applied in Nanomaterial Properties for Nano security." *Journal of Nanomaterials* 2022 (2022).

[11] K. R. K. V. Prasad, Ravindra Kollu "Multi-Objective Approach for Optimal Placement of DG and Capacitor Along with AVR In Distribution Network", JARDCS,1943-023X.

[12] K. R. K. V. Prasad, Ravindra Kollu "Optimal Allocation of DG and Capacitor in Distribution Network Using NSGA-II", Journal of Test Engg& Mgt,18076-18083.

[13] K. R. K. V. Prasad, Ravindra Kollu "Optimal Conductor Selection and Capacitor Placement for Cost Minimization in Distribution Systems", IJASRM,2455-6378.

[14] K. R. K. V. Prasad, Ravindra Kollu "Simultaneous DGand Capacitor Placement for Energy Loss Minimization with Constant and Time Varying Load Profile", International Journal of control theory and applications,0974-5572.

[15] K. R. K. V. Prasad, Ravindra Kollu "Optimal Allocation of AVR & DGs In Distribution Systems Using HSA", International conference MCCS-19.

[16]K. R. K. V. Prasad, Ravindra Kollu "A Multi-Objective Approach for Optimal DG And Capacitor Placement", International conference ICSEG-16.

[17] M. Singh, and A. Chandra, "Real Time Implementation of ANFISControl for Renewable Interfacing Inverter in 3P4W Distribution Network," IEEE Trans. Industrial Electron, vol. 60, no.1, pp. 121-128, Jan. 2013.

[18] M. Qasin, P. Kanjiya, and V Khadkikar, "Artificial-neural network-based phase-locking scheme for active power filters," IEEE Trans. Power Electron., vol. 61, pp. 3857 – 3866, Aug. 2014.