

An Energy Saving Green Plug Device for Nonlinear Loads

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Abstract. The paper presents a low cost a FACTS Based flexible fuzzy logic based modulated/switched tuned arm filter and Green Plug compensation (SFC-GP) scheme for single-phase nonlinear loads ensuring both voltage stabilization and efficient energy utilization. The new Green Plug-Switched filter compensator SFC modulated LC-Filter PWM Switched Capacitive Compensation Devices is controlled using a fuzzy logic regulator to enhance power quality, improve power factor at the source and reduce switching transients and inrush current conditions as well harmonic contents in source current. The FACTS based SFC-GP Device is a member of family of Green Plug /Filters/Compensation Schemes used for efficient energy utilization, power quality enhancement and voltage/inrush current/soft starting control using a dynamic error driven fuzzy logic controller (FLC). The device with fuzzy logic controller is validated using the Matlab / Simulink Software Environment for enhanced power quality (PQ), improved power factor and reduced inrush currents. This is achieved using modulated PWM Switching of the Filter-Capacitive compensation scheme to cope with dynamic type nonlinear and inrush cyclical loads..

1. Introduction

Fuzzy Logic Control is utilized as the PWM dynamic switching/regulation scheme for the SFC-GP FACTS Device used to enhance power quality and energy utilization for single phase nonlinear loads. It has key advantages compared to other classical PID controller. The advantages of FLC are simplicity, low cost and flexibility in case of uncertain load with unknown mathematical model or process dynamics [1], [2], [3], [4]. Power quality (PQ) problem is defined as any variation in frequency, current or voltage that may lead to an equipment malfunction or failure [5]. In a modern electrical distribution/utilization system, there has been a continuous increase of nonlinear loads, such as uninterruptible power supplies, rectifier equipment used in domestic appliances, communication networks, motors, adjustable speed drives, etc. [6], [7], [8], [9]. Power Quality related problems are of most concern nowadays. The widespread use of electronic equipment, such as programmable logic controllers (PLC), information technology equipment, and power electronics such as adjustable speed drives (ASD), energy-efficient LED-lighting, led to severe nonlinearity and varying range of electric loads nature. All the victims of power quality will be caused by this load. Due to their non-linearity, all these loads cause disturbances in the voltage and current waveform [1]. Whatever the power factor is, however, the generating authority must install machines capable of delivering a particular voltage and current even though, in a specified case, will not most of the voltage and current products is being put to good use also for improving the efficiency, reactive compensation using the capacitors is utilized to improve power factor and reduce harmonic content in Nonlinear- load current [9]. A modulated/switched tuned arm filter is utilized to reduce harmonic currents to reduce cost and simplify



Filter topology [6], [7]. The major thought of filters is to reduce the amount of harmonic in order to improve power quality. The characteristic of passive filters are mainly considered as active alternatives to reduce current harmonic to enhance power factor correction. The disadvantage of passive filters is not modified to follow the dynamic behavior changes of non-linear loads [10]. The advantages of passive filters are terminal voltage regulations, voltage variation reduction, and voltage balance improvement in three phases [11]. The limitations of fixed structure/fixed parameter and detuned passive filters causing series/parallel resonance between system, capacitors and existing AC supply impedance is fully documented. The low-cost passive filter can be utilized with simple switching devices to enhance both dynamics, bandwidth and operation with slow dynamic cyclical and inrush type nonlinear loads. Effective control using PWM- switched power LC-filters can improve effectiveness of passive filter compensation [8], [10]. Enhancement of power quality and improvement of power factor have been proposed in many configurations and literature of filters [12], [2], [3]. Fuzzy system control (FLC) is most suited for control of the pulse width modulation to overcome the negative effects of system nonlinearities and dynamic load variations and variable-uncertainties [13]. A low-cost GP-SFC, C-type scheme has implemented and extended to improve the power quality and efficient utilization in smart utilization grid application. The proposed MNFC- based single phase filter utilizes multi loop dynamic error driven fuzzy logic-FLC to control the SFC-GP FACTS device. The proposed scheme has implemented and succeeded in power factor enhancement and power quality improvement, and full limiting transient over voltage and inrush current conditions. The scheme can be extended to three phase systems [14].

2. Overall system design

A single-phase AC utilization system which is driving an arc type load is shown in figure 1. By analyzing figure 1, we can divide the AC single-phase system into three components namely single-phase power source, the modulated green plug filter and the nonlinear load. The load in the system is the source of nonlinearity and generates harmonics in the power line. Such transients and input current excursions generated by the load need to be compensated and in this study, we have designed a green plug filter to perform this compensation task. The proposed green plug filter is placed in parallel with the load as shown in figure 1. The inner construction of the green plug filter is shown in figure 2. In order to optimally control the operation of the filter, we have deployed a two-input fuzzy logic controller which is inherently a nonlinear controller and is robust to disturbances. The block diagram of the fuzzy logic controller is shown in figure 3 with its inner construction depicted in figure 4. The fuzzy logic controlled green plug filter will make sure that the energy is utilized efficiently, and the power quality is also improved [15].

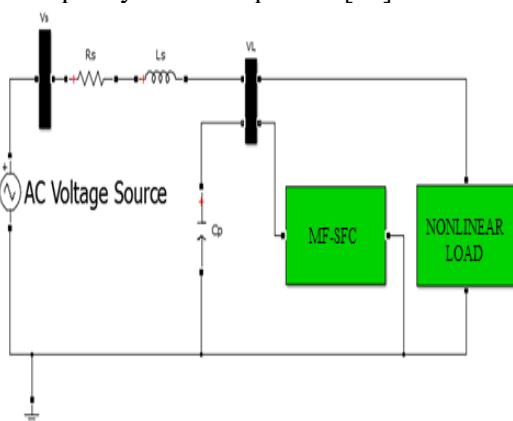


Figure.1. The components of a Single-phase Utility System.

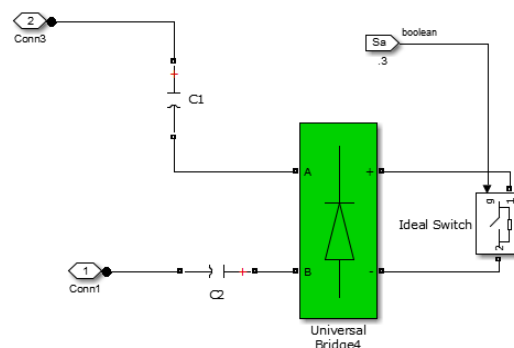


Figure 2. The structure of green plug switched filter

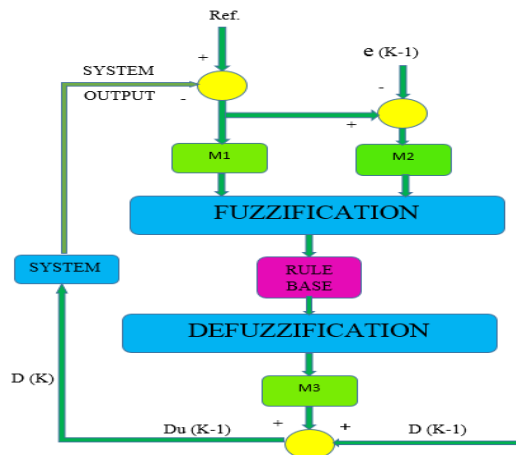


Figure 3. Proposed fuzzy logic controller for green plug filter

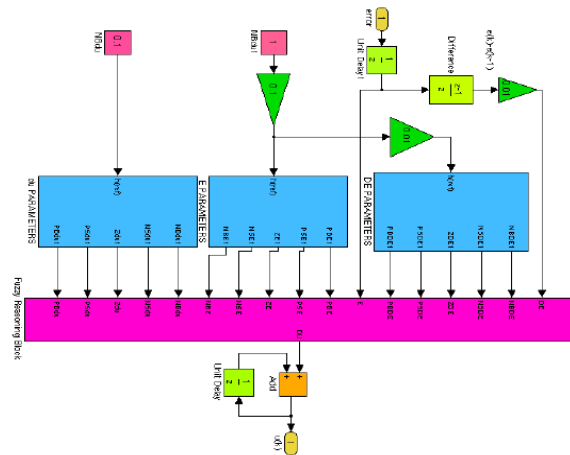


Figure 4. Simulink diagram of fuzzy logic controller

		Δe				
		NB	NS	Z	PS	P
e	PB	Z	PS	PS	PB	PB
	PS	NS	Z	PS	PS	PB
	Z	NS	NS	Z	PS	PS
	NS	NB	NB	NS	Z	PS
	NB	NB	NS	NS	NS	Z

Figure.5. Rule- base design of the fuzzy logic controller

3. Operation of fuzzy logic controller

We will now briefly describe the operation of the two-input, single-output fuzzy logic controller. The fuzzy logic controller accepts the error and change in error as its inputs and produces the control signal for the green plug filter as its output. First, the two inputs are fuzzified using five triangular membership functions. Here, we have preferred triangular membership functions over other types of membership functions such as Gaussian and bell curves as we want to reduce the computational complexity of the controller-driven-filter. After the inputs are fuzzified, a rule base is created to empower the controller with human intelligence. This rule base is shown in figure 5. As can be seen from this figure that all possible combinations of the input membership functions are utilized to construct the rule base. The operation of the rule base can be explained in terms of the sliding mode control theory [16]. As an example, the diagonal line of the rule base is a sliding surface which is the resting state of the system. This sliding surface will be reached after the fuzzy controller will drive the states from other regions towards this surface which is the reaching phase of the system. Once the system will reach the diagonal line, fuzzy logic controller will keep the system onto this line. This means that the equilibrium will be reached and maintained by the fuzzy logic controller. The final stage in fuzzy controller design is known as defuzzification which transforms the linguistic output into a crisp output which can then be fed to the green plug filter. In order to generate the crisp output, we

have used Takagi-Sugeno inference mechanism with singleton output variables. The other mechanism is known as Mamdani but it is more complex than the Takagi-Sugeno so we have preferred Takagi-Sugeno keeping in view the online operation of the green plug filter. Here, it is pertinent to mention that the output from fuzzy logic controller are added to its previous output which employs that we are forcing an integral action in the system. The reason of using integral action to eliminate the error completely during the steady state operation of the filter-driven-load system [17].

4. Simulink construction of fuzzy logic controller

We have simulated the complete system in Simulink environment. Here we will briefly discuss the construction of Simulink based fuzzy logic controller. The inputs to the controller are error and change in error. For the change in error, we employ unit delay block and by subtracting the output of the unit delay block from the error signal, we obtain the change in error input signal. Then from the Fuzzy Logic Toolbox in Simulink, we construct the rule base using membership function blocks along with the maximum and minimum operators. Then the output singletons are cut at the minimum level and summed up to generate the incremental control signal. This incremental control signal is also delayed with the help of unit delay block and added with the current control signal to produce the final output. Three scaling elements are also used in the design of fuzzy logic controller. Two of these gain elements are used with the input and one is used with the output. This is to adjust the response of the fuzzy logic controller in relation to the peak values of the error, change in error and the output control signal [18]. Without these gain adjustments, the optimal operation of the filter was not achieved. In this study, we are tuning these factors manually, but this process can be automated and will be considered as a future work.

5. Simulation Results

In order to check the effectiveness of the proposed green plug filter, we conduct the simulations in MATLAB/Simulink environment with several types of the nonlinear loads. The results of the simulation are shown in Figs. 6 through 13. The simulation results include the waveforms for voltage, current, active power, reactive power and the frequency spectrum for each type of load. It can be seen that the green plug switched filter is effective in improving the power quality and reducing the inrush currents due to several types of loads present in the industrial environment.

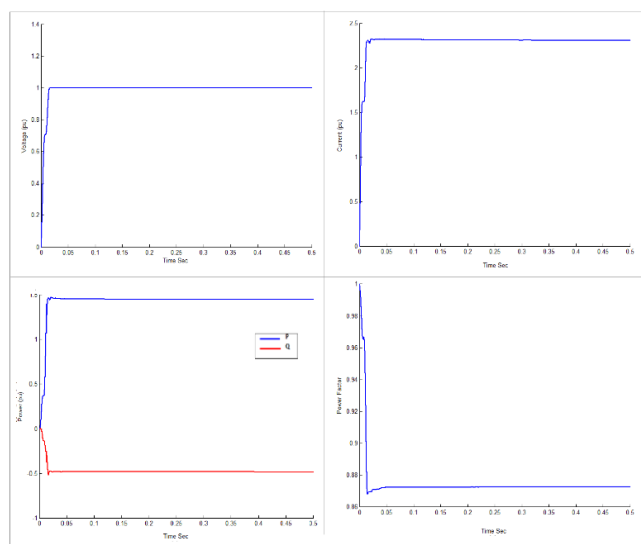


Figure 6. Nonlinear load-RMS V, I, P, Q and PF values at AC source bus.

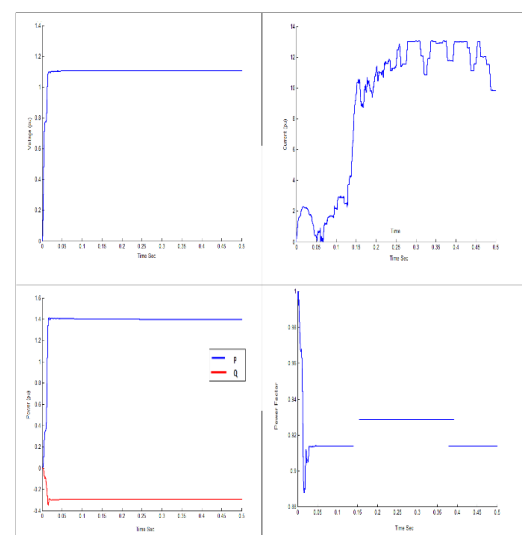


Figure 7. Nonlinear load-RMS V, I, P, Q and PF values at AC load bus

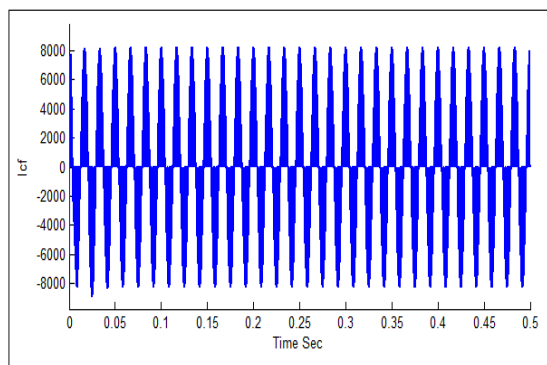


Figure 8. Nonlinear load-Capacitor filter current variation.

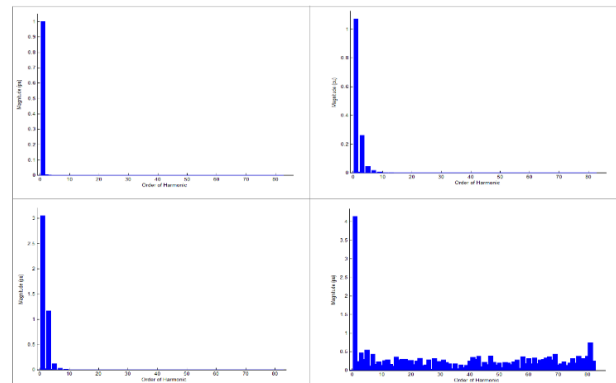


Figure 9. Nonlinear load- FFT frequency spectra of V and I waveforms at both source and load sides

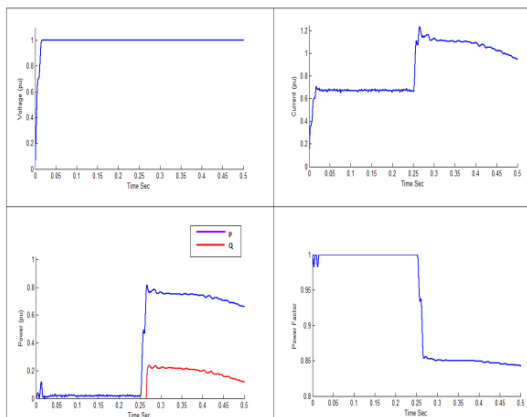


Figure 10. Induction motor cyclic load (full load)-RMS V, I, P, Q and PF values at AC source bus.

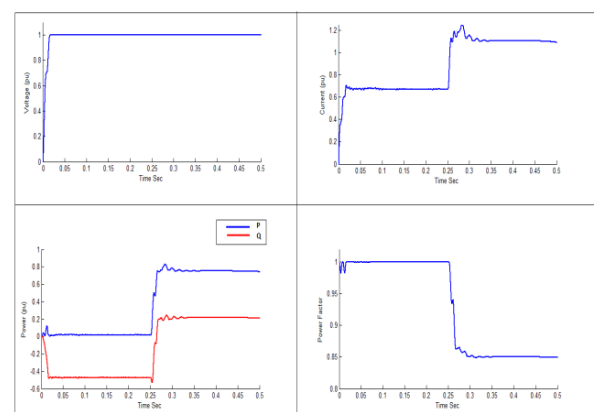


Figure 11. Induction motor cyclic load (full load)-RMS V, I, P, Q and PF values at AC load bus.

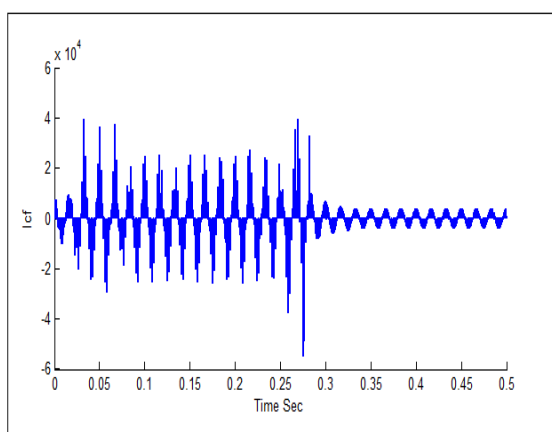


Figure 12. Induction motor cyclic load (full load) Capacitor filter current variation.

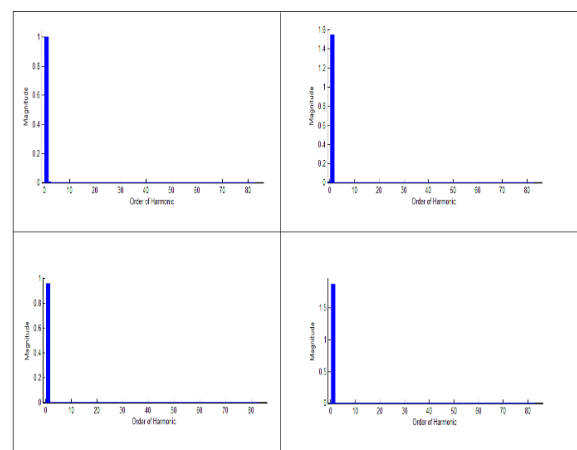


Figure 13. Induction motor cyclic load (full load)-FT frequency spectra of V and I waveforms at both source and load sides

6. Conclusions

This paper presents a FACTS based Green Plug-Switched Filter Compensation SFC_GP scheme controlled by a dynamic multi-loop error driven Fuzzy Logic Controller. The SFC-GP is validated using the Matlab /Simuink Software Environment and the fast-acting Dynamic Fuzzy Logic Controller. The SFC-GP device is controlled by a dynamic tri-loop error driven FLC controller. The SFC-GP Device with Fuzzy Logic Controller is scheme validated for enhanced power quality, voltage stabilization, and efficient utilization. The SFC-GP FACTS Device using a PWM-Switched Filter Compensator scheme is very suitable for nonlinear inrush, dynamic, cyclical and motorized loads efficient electric utilization and power quality/power factor/harmonic reduction. Starting Scheme for voltage stabilization/reduced inrush currents and power factor It can be extended to 3 Phase Nonlinear Loads and utilized for Voltage Dynamic Stabilization with hybrid Smart Grid-Renewable Energy interface schemes using PV/Wind/Fuel to reduce transient voltages, ensure soft starting, limit inrush currents and flicker control. The SFC-GP Device topology can be modified as well as the control strategies to suit specific applications and control duties using fixed topologies as well as modified optimized structures of soft-computing ANN/NFIS/GA/PSO regulators with optimal Gain Scheduling and modified weightings.

7. References

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