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Implementation of Solar Photovoltaic System with Universal Active Filtering Capability

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Abstract

In this research work presents a fuzzy logic controller (FLC) for a solar photovoltaic (PV)-based universal active filter (UAF) is implemented to enhance quality of power in a distribution system. Power quality problems, including harmonic distortion, voltage sag, and swell, are eliminated with PV-UAF Controller. The UAF's functioning is regulated by the fuzzy logic controller in order to successfully address these power quality challenges. Through simulations and experiments, the suggested system's performance is assessed. These indicate how efficiently it works to improve the distribution system's power quality. The proposed system is implemented and tested by using MATLAB/SIMULINK software. The outcomes demonstrate that the suggested approach is successful in enhancing power quality and lowering harmonic distortion.

Keywords: Power quality, Fuzzy controller, solar photovoltaic array, Universal Active Filter (UAF), Harmonic disturbances, Inverter, Grid, Harmonic distortion reduction.

I INTRODUCTION

The power plants like wind solar and combination of two power systems (hybrid) are the most reliable source of RES. To maximise its power, a RES is always connected to a battery bank. Researchers have opted to connect RES to the grid due to issues with chemical batteries, such as chemical contamination and expensive start-up costs. While connecting RES to the grid, there are a number of concerns that must be addressed, such as problems with power quality, dependability, protection, and stability. But now that semiconductor technology has advanced, all of these issues are fixed. Researchers have linked RES to problems with chemical batteries because of issues including chemical contamination and high starting costs [1]. When connecting RES to the grid, there are a number of concerns that must be addressed, including problems with power quality, dependability, protection, and stability. But with the development of semiconductor technology, all of these problems are resolved. However, the growth of non-linear loads fed by power electronics at the PCC means that power quality issues continue to be a major problem. [2]For a very long time, Non-renewable energy resourceshave been utilized for primary source for electrical Energy, but this has a number of disadvantages because of their scarcity, exhaustibility, and inability to be recycled. Additionally, they increase pollution, which helps to increase the risk of global warming. [3] People are generally employing more environmentally friendly and sustainable technologies as a result. PV-based systems are widely used in a range of applications because they are increasingly well-liked and technologically advanced as alternatives to traditional energy sources. It is paired with the MPPT algorithm in order to assure the highest PV system efficiency. PV systems are modelled using MPPT techniques. [4]
The PV system uses an increasing conductance to maximize the amount of energy utilized by the SPV array, the (MPPT) method is used. The load controller is in charge of storing surplus electricity and discharging when there is no power from solar PV [5]. Due to lower magnitudes of solar power a boost converter is

employed to increase those magnitudes. To increase the electrical distribution systems' capability for long-term compensation. [6].

By combining the Advantages of clean energy with improved power quality and incorporation of RES using technologies like the distribution static compensator, (DVR), and (UPQC) (DSTATCOM) offers a practical alternative. Shunt (VSC)-based systems have been the focus of the majority of research on RES with better quality of power. In [7, 8], by connect solar generation system with voltage source converter, it operated like a DSTACOM. By using this it improves the Power quality issues [9]. A unique topology for DVR systems with fewer switches has been presented. Although DSTATCOM has the ability to regulate voltage, it must do so by using PCC reactive power. [10]

In addition, the load cannot be isolated from harmonics in the PCC voltage by DSTATCOM. According to IEEE standard 512-2014 [11], [12], the overall harmonics cannot be more than 5% for the majority of electrical equipment to function correctly. While they have a number of drawbacks, passive filters have been employed extensively to reduce THDs. Network resonance issues arise when the number of harmonics to be eliminated rises, and the design typically gets more challenging. The harmonics that are obtain from DC to DC Conversion can be eliminated by usingAPF. Because PV systems are expensive to install, getting as much electricity as possible from them is recommended [13].

A few of the variables that determine how efficiently the PV-APF produces power in a real system include temperature, irradiance level, and the PV system's setup [14]. Numerous studies are looking into how PV-APF-based systems operate in different inverter configurations. Analysis of PV APF-based systems' performance is done using various configurations developed using SIC, MSIC, and CIC. A universal power quality conditioner (UPQC) is included in 3-phase PV systems. In addition to having the ability to enable voltage regulation and harmonic compensation, this device offers the advantages of series compensator and shunt compensators. The DQ theory based controlling along with filters can be employed in PV systems.

Generation, transmission, and distribution comprise the three parts of the power system's distribution side. Using additional transmission lines, the distribution side distributes the power systems to various loads. Power quality is essential to power system when a load receives varied power. The low-quality power has an effect on residential and commercial customers with complex loads. On the distribution side, there are many different kinds of loads, but sensitive loads are more affected by low power quality than other loads.

A shunt active power filter was developed by researchers after many years of work to address problems with non-linear loads. The authors of article [17] added The RES interfacing inverter's added capability through the (SAFs)in order to avoid buying additional hardware equipment at a higher cost.

The enhancement of power quality in grid current and management of voltage can be done by employing PV-UPQC that consists of series and shunt VSC. Concerns about power quality(PQ) can be completely addressed by UPQC on both the load and PCC sides. By using PV with shunt APF it provides multiple advantages like power quality issues reduced and continuity power supply [19].A detailed examination of various UPQC controls and settings Long-term, current-based rectification is combined with clean energy power generation in the proposed PV-UPQC architecture.

PV-UAPF act as series active filter and used as a series regulator to control voltage in the system [20]. As proposed in [21, 22] FACTS devices like SVC are used to compensate reactive power [23] in the transmission system [24]. Active power filters have the capacity to dynamically correct for disturbances carried on by both the source voltage and the attached loads that are non-resistive and non-linear. [25] Have replaced passive power filters as the most commonly used power electronics components. Series and shunt connector filters are known as classification for APF, parallel active filters (PAF), DSTATCOM. These parts are made to protect the grid against reactive power losses as well as harmonic loads and other types of industrial disturbances.

The filters consists of dynamic voltage regulators and series-connected active power filters (DVR). The utilization of above devices can be able to get rid of PQ issues,the series and shunt related terminologies are meant to lesser the variations related to installation location and compensation. Both sets of terminologies function similarly and are based on the same operational principles. Numerous literary forms have used a variety of terminologies according on the situation, ease of use, and compensating objectives.

In this research project, we introduce a novel fuzzy logic controller (FLC) and compare it to other traditional methods in order to enhance PQ performance. The use of an FLC-PV-based UAF improved system voltage stability and reduced power oscillations. The FLC operates according to rules. Fuzzification, defuzzification, and rule basis are the three components of FLC. Additional parts go through the planned FLC's specifics.

The organisation of the paper is as follows: The literature review and introduction of the system is depicted in Section I, the system descriptionof the system is mentioned in section II, whereas section III describes the proposed method and section IV explains about the results that are obtained by implementing proposed method and the last section ends with conclusion

II SYSTEM DESCRIPTION

The below figure-1 depicts the system description of the UAPF. In this three-phase, two-stage arrangement, a step up converter connects the PV array to UAPF's DC. The distribution system and the compensators are connected by filter inductors. Through series transformers, by series controller, it injected voltage in series. During switching operation in the system, both shunt and series VSCs require ripple filters to eliminate higher-order harmonics generated. Which are commonly built from connected series resistors and capacitors.

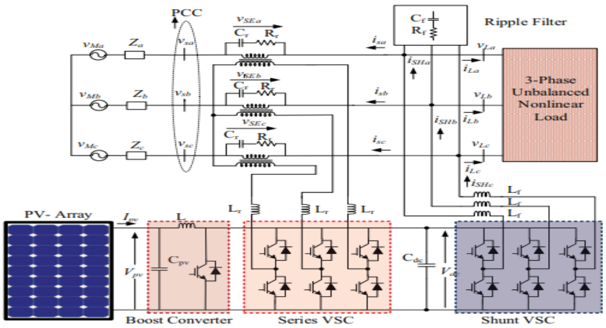


Fig. 1. System configuration of UAPF-

The proposed PV-UAPF provided harmonic reduction and continuity power supply in the DS. In addition to enhancing the quality of the power, UAPF-PV also produces energy by integrating PV electricity into the distribution system. Further operation and control topology provide.

B. Controlling SAFs Configuration

Fig 2 (a) and (B) shows the filter and controller diagrams for proposed PV-UAPF. The below equations shows the open loops transfer functions for proposed systems.

$$G_{sosf}(S)=\frac{K_1K_2}{(s-j\omega'+K2)(s-j\omega')} \quad 1$$

Following are the details of 1 closed loop transfer function.

$$Gcl_{sosf}(S)=\frac{K_1K_2}{(s-j\omega'+K2)(s-j\omega')+K_{1K_2}} \quad 2$$

K1 and K2 are the two controlling gains for this structure. The stability and dynamic reactivity of the basic positive sequence component are shown by the connection between the values of K1 and K2. [11] Provides a thorough evaluation of the filter gain setting. The needed grid current is accurately represented by the shunt compensator reference signal. Grid currents for PV power (Ipvg), grid currents for basic active load power (ILp), and loss components for losses caused by the firing of the switches, filter losses, etc. comprise the three primary active components that make up the grid current magnitude. The equation below results in this:

$$I_s^* = I_{Lp} - I_{pvg} + I_{loss} \quad 3$$

The load current of the proposed system is calculated by using this control topology. The provided load positive current by commuting grid current as follows

$$I_{Lp} = K^{'} \times I_{Lap} \quad 4$$

Where

$$K = \frac{V_L^*}{V_s} \quad 5$$

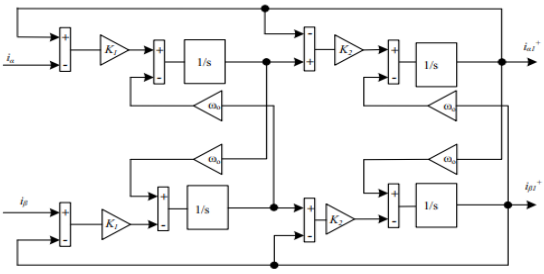
Here VL* is reference load voltage and Vs is supply voltage

The amount of grid current necessary to produce PV power is calculated using the equation below:

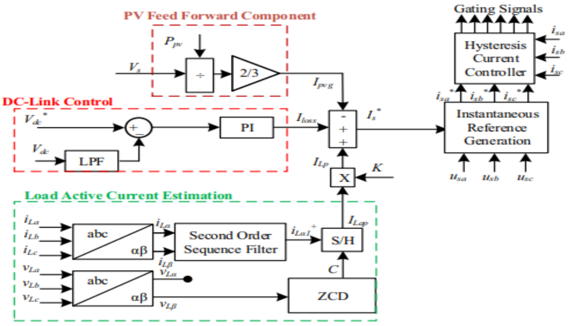
$I_{pvg} = \frac{2}{3}\frac{P_{pv}}{V_S}$ 6

Where PV array power is denoted by Ppv and PCC voltage is denoted by Vs the desired level of voltage is maintained on the UAPF-DC-bus PV using a proportional integral (PI) controller. By using PI controller The Iloss is calculated from below equation

$I_{loss}(n) = I_{loss}(n-1) + K_p\left(\Delta e_{vdc+K_i} e_{vdc(n)}\right)$ 7



(a)Proposed APF structure



(b) Proposed Shunt controller controlling

Figure 2. Shunt Compensator Control Using a Sequence Filter of Second Order

The Vpcc is given by below equation

$V_s = \sqrt{\frac{2}{3}\left(V_{sa}^2 + V_{sb}^2 + V_{sc}^2\right)}$ 8

$u_{sa} = \frac{v_{sa}}{V_s}, u_{sb} = \frac{v_{sb}}{V_s}, u_{sc} = \frac{v_{sc}}{V_s},$ 9

The reference Shunt active controller currents is given by

$i_{sa}^* = I_S^* \times u_{sa}, i_{sb}^* = I_S^* \times u_{sb}, i_{sc}^* = I_S^* \times u_{sc}$ 10

The difference between actual and reference current

$(i_{sa}^*, i_{sb}^*, i_{sc}^*)\ and\ (i_{sa}, i_{sb}, i_{sc})$isgiven to a hysteresis controller, which produces gating pulses to operate the shunt compensator.

Controlling the Series Active Filter's configuration

The below fig.3 shows the control structure of proposed Series Controller. The below equations provide the instantaneous reference load voltages:

$v_{La}^* = V_L^* \times u_{sa}$ 11

$v_{Lb}^* = V_L^* \times u_{sb}$ 12

$v_{Lc}^* = V_L^* \times u_{sc}$ 13

The calculated reference voltages are further converter into α – βreference frame.

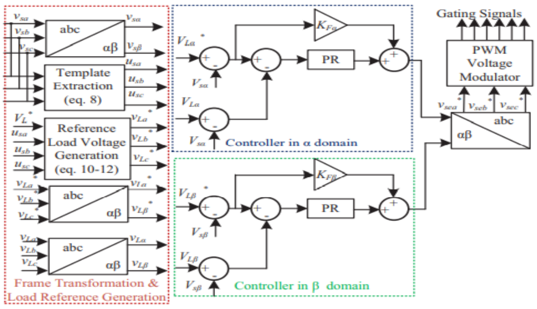


Figure 3. Structure of the Series Active Filter Control.

Two PR controllers are used to generate reference series active filter voltages are given below:

$$v_{se\alpha}^{*} = v_{L\alpha}^{*} - v_{s\alpha} \quad 14$$

The SAF voltage (vseα) is obtained as

$$v_{se\alpha}^{*} = v_{L\alpha} - v_{s\alpha} \quad 15$$

The feedback control path's output is merged with the PR controller's output. The PR controller takes into consideration filter circuit drops that aren't taken into account while determining references, whereas the feedforward approach gives the primary component of the control signal.In the domain, the control function is executed in exactly the same manner. Later by using PWM generator, produces gate pulses to control Series active filter.

Controlling of Boost Converter

Generally Solar system produces low magnitude.To increase output of PV system, boost converters are utilized [15]. The different types of MPPT topologies are available to control boost converter operation. In this research work employed P&O method for produce duty cycle for boost converter.

$$d_{boost}(n+1) = d_{boost}(n) + D_{step}.sgn(\Delta P_{pv}) \quad 16$$

III PROPOSED METHOD

The proposed method employed Fuzzy controller to control operation of PV-UAPF. On an actual solar PV-UAF system, the proposed fuzzy controller is used, and its performance is tested under various operating conditions. The effectiveness and dependability of the system as well as the power quality are found to be improved by the suggested technique.

Figure 4 shows a schematic illustration of such an FLC. The Fuzzifier, interference engine, and defuzzifier are three crucial parts of the FLC's structure, as represented in the following diagram. The two inputs are transformed into fuzzy sets between 0 and 1 by the MFs (i.e., membership functions) in the Fuzzifier during the Fuzzification process.

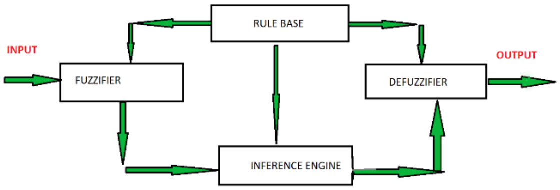


Fig 4. Fuzzy logic controller

Figures 5, 6, and 7 display the FLC membership procedures and guidelines that were used in this study. Zero (Z), Positive Big (PB), Positive Medium (PM), Positive Small (PS), Negative Big (NB), Negative Medium (NM), and Negative Small are the seven different types of linguistic variables that are employed in this study to analyze the overlap. MF's triangular variation is also utilised (NS).

RULE TABLE-1

e/de	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

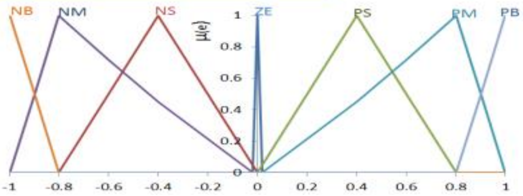


Fig. 5. Input-1 Error (e)

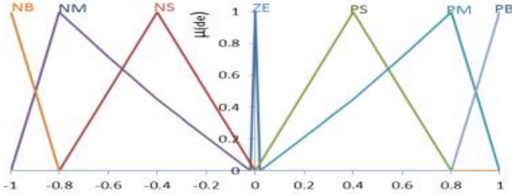


Figure 6. . Input-2 Change error (de)

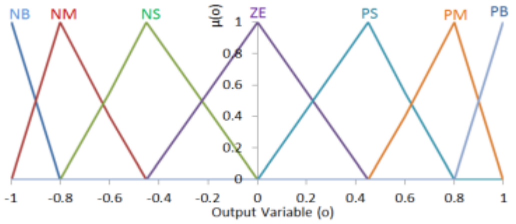
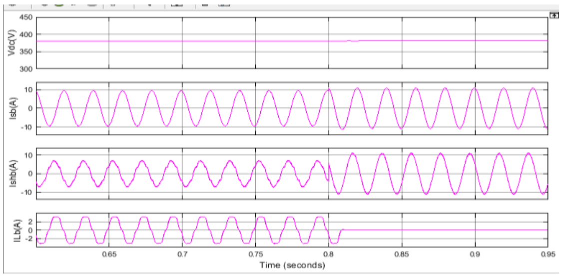


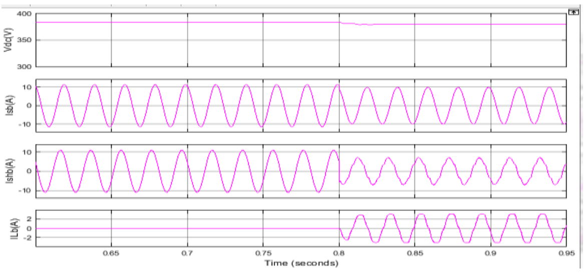
Figure 7. Output variable (o)

The seven fuzzy levels PS, PM, PB, NB, NM, NS and ZE are shown in Figures 5, 6, and 7. There is one of these levels assigned to each input and output variable (zero). A rule table is created based on experience, as seen in Table I. On the basis that when input error is large, control output should be high, and when it is small, precision control is necessary, rules are developed.

V RESULTS AND DISCUSSION

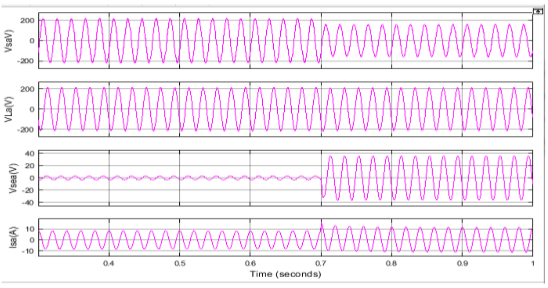


(a)Performance with Load Removal

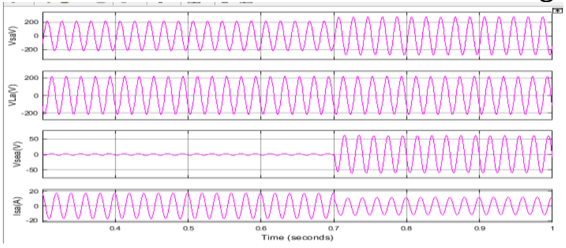


(b)Performance with Load Addition

Figure 8. Dynamic Performance under an Unbalanced Load



(a)Performance in the Presence of a PCC Voltage Dip



(b) Performance in Swelling Conditions

Fig. 9. Dynamic Behaviour in PCC Voltage

Rise/Drop Conditions

Fig 8 (a), (b) and fig 9 (a), 9 (b) shows the proposed system dynamic performance under unbalanced load and voltage rise/drop conditions. In Fig 8a connected load suddenly removed at 0.8 seconds. Then shows how proposed system operates under sudden removal of load. In fig 8b addition of load suddenly at 0.8 seconds. Then shows how proposed system operates under sudden removal of load. In Fig 9a suddenly voltage sag appears at 0.7 seconds. Then shows how proposed system operates under voltage sag condition. In Fig 9b suddenly voltage swell appears at 0.7 seconds. Then shows how proposed system operates under voltage swell condition.

parameter	**Case1: Load removal**	**Case2: Load Addition**	**Case 3: Under Sag condition**	**Case4: under swell**	**Case5: under Irradiation Change condition**
Isabc with PI	2.62%	2.59%	4.91 %	4.32%	3.68%

ILabc with PI	21.46%	21.47%	21.65%	21.77%	21.47%
Isabc with fuzzy	0.75%	0.58%	3.91%	3.12%	2.24%
ILabc with fuzzy	8.59%	6.33%	8.23%	7.96%	6.32%

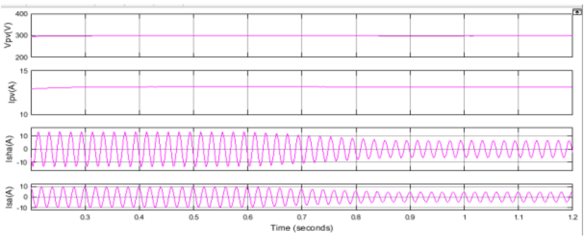


Fig. 10. Proposed system Response under Solar irradiation Variation

Fig 10 shows the proposed system performance under solar irradiation variation condition. In this condition input supply of the PV system suddenly experiences with sudden change in sun energy. The above simulation results shows, how proposed system experienced this type of condition.

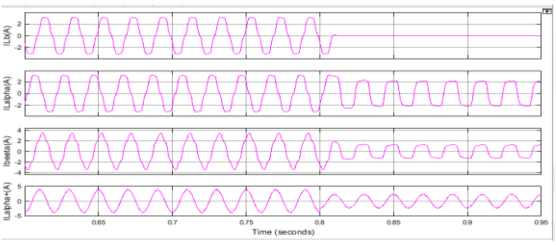
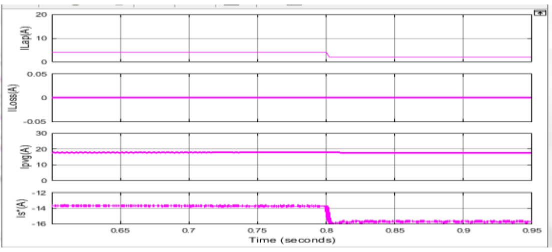
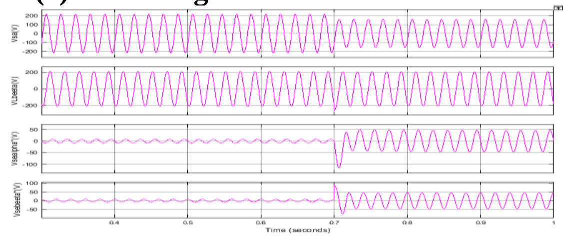


Fig. 11. Generated Load Currents

Fig.11 Shows the Generated Load currentsfor proposed system. In this case the proposed system experienced with different disturbances. So the generated output currents changed rapidly from 0.8 seconds.



(a)Control signals from Shunt controller



(b)Control Signals from series controller

Fig. 12. Control signals from PV-UAPF

The fig 12 shows the control signals from PV-UAPF. Fig 12a shows how shunt controller generates control signals under different disturbances. Similarly Fig 12b shows how series controller generates control signals under different disturbances.

THD comparison table for conventional method and proposed method

V CONCLUSION

By using a FLC to regulate the operation of the UAF, the suggested system successfully removes PQ related such as harmonic distortion, voltage swell and sag. Through simulations and experiments, the suggested system's performance was assessed, and the results show how well it works to increasePQ throughout the distribution network. The proposed technology, which would improve PQ in distribution systems, uses solar energy as a source of electricity, making it sustainable and friendly to the environment. The proposed system can be applied to a variety of settings, including residential, commercial, and industrial ones, and it has a great deal of potential for use in actual power systems.

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