Effective Power Quality Improvement in PV Grid by using Adaptive Hysteresis Dynamic Active Power Filter Under Different Source Voltage Control Strategies

Suresh Penagaluru, Gowri Manohar. T

Abstract: ***With the modernization of loads using power electronic components and dynamic loads diminishes the power quality of the system. Integration of renewable energy sources is the best solution to meet the additional power demand and also to improve the power quality problems like low power factor and harmonics distortions. In this paper, an adaptive dynamic shunt active power filter is proposed to alleviate the power quality problems like current harmonic distortions and reactive power compensation. The proposed control strategy performance is examined under different source voltage conditions under IEEE standards. Photovoltaic system is integrated at DC link of the Adaptive dynamic shunt active power filter. Proposed system performance is studied by using MATLAB/SIMULINK Environment.***

Keywords: Power Quality, Renewable Energy Sources, Active Power Filters, Adaptive hysteresis controller, ANFIS Controller.

I. INTRODUCTION

Now a day's new evaluations in industrial and commercial loads using power electronic components raises the power quality issues. Gradual increasing of dynamic loads more burden on grid. To meet the load demand utilities are depends on conventional sources [1 2]. It drastically increases the pollution. To meet the extra load demand, pollution free renewable energy sources plays prominent role.

Integration of renewable energy sources is the major challenge to existing grid. Renewable energy source integration and nonlinear loads are the major causes of power quality issues like current harmonics, unbalance voltages and low power factor [3-5], etc...

To alleviate these issues FACT devices plays major role in distribution system. Installation of Dynamic shunt Active power filters is one of the solution for increase the power factor by reactive power compensation and reducing the current harmonic distortions due to nonlinear loads [6-8]. To compensate these issues different active power filter control strategies were proposed. In [9] authors presented PI based dq control for grid connected PV system. Here, %THD of 5.38 % is achieved. In [10], authors compared Fuzzy based pq and dq controllers to compensate the current harmonics. In [16], authors proposed ANFIS based ICC controller for reactive power compensation and harmonic reduction. Here attained % THD is 2.32. In [4] authors proposed modified dq control for harmonic reduction. Here, %THD attained is 3.87. In this paper we proposed adaptive dynamic shunt active power filter to compensate the current harmonics and improves the power factor. For further reduction of harmonics an adaptive HCC based dynamic shunt active power filter (DSAPF) is proposed to produce reference current signals. This modified dq control DSAPF is supply by suppressing the current harmonics and improves the power factor within the standard limits of IEEE 1549.

Paper has been organized as, Section I presents Introduction to power quality. Proposed methodology is described under section II. Section III presents simulated results for the proposed controller. Final conclusions presented in section IV.

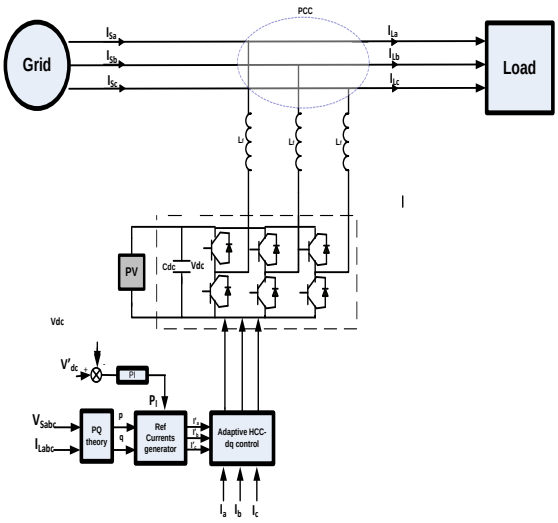

Fig.1 Adaptive DSAPF Controller based PV fed Mdq-Three Phase System

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II. Proposed Control Strategy

Figure 1 presents proposed 3 phase system. A Nonlinear load is supplied by utility where harmonics have been introduced into source current. To suppress these harmonics and compensate the reactive power, the shunt active filter is connected at PCC[12].

A. PV Unit

The proposed photovoltaic source is connected to the DC link for providing the power required by DSAPF to achieve the desired results. The PV unit includes DC / DC boost converter, MPPT Controller and PV cell [13-14]. Many MPPT methods are available [15]. Among them, frequently used MPPT technique is Adaptive Neuro fuzzy inference (ANFIS) controllers . This method has better advantage to control Parameters Figure 2 presents PV Module and Figure 3 equivalent circuit of the solar cell. The adaptive neuro-fuzzy controller helps in better evaluation of tracking maximum power point compared to traditional techniques. The advantages of the ANFIS based MPPT method is fast response, better advantage to control parameters and utilizing PV modules in more efficient way[16].

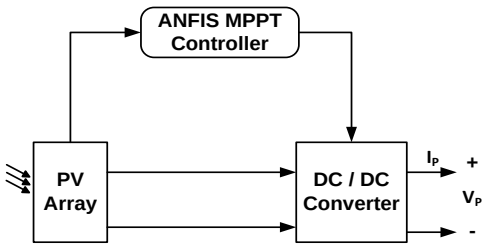


Fig 2 Solar PV MPPT Controller

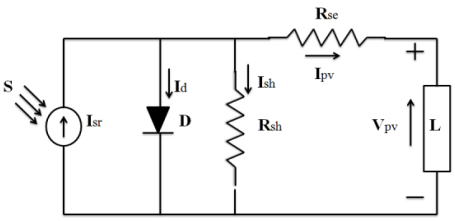


Fig 3: Equivalent circuit of PV Cell

III. Shunt Controller

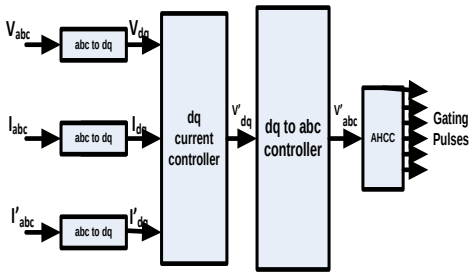


Fig 5 . Modified dq Current Control Scheme.

Figure 5 shows the Modified DQ Control Strategy. In this control strategy, initially supply currents (Isa ,Isb ,Isc), Power generated from PV source is given by Eqn. (2.1)

$$P\_pv=V\_pv*I\_pv \tag{2.1}$$

PV Source voltage and current are given in Eqn.(2.2) & (2.3),

$$Vp= AkT/q \ln\{I\_sc/I\_p +1\} \tag{2.2}$$

$$I_p = I_{sc} - I_{sat} \exp\left[\frac{q}{AkT}(V_p + I_p R_{\_se}) - 1\right] - \frac{V_p + I_{sc} R_{\_se}}{R_{\_sh}} \tag{2.3}$$

Here, R_sh= Shunt Resistance, R_se= Series Resistance, A = Diode Ideality Factor and k = Boltzmann constant.

B. ANFIS Controller

Figure 2 shows Adaptive fuzzy system which is used for tracking maximum power point in this paper. The inherent ability and fast tracking capability of ANFIS controller reduce the steady state error comparing the conventional controllers. it composes both Neural Network's & Fuzzy logic [17]. The 5 layer ANFIS structure is used in proposed model which is shown in Figure.4 and sugeno rules are used to reduce the differential error. Here, In [18] ANFIS learning is two directional learning. Least Square Error learning is used for the forward learning process. Back propagation learning is adopted in backward direction. Current ANFIS model, 3 fuzzy linguistic variables are selected (Low, Medium and High) for two input and single output variables.

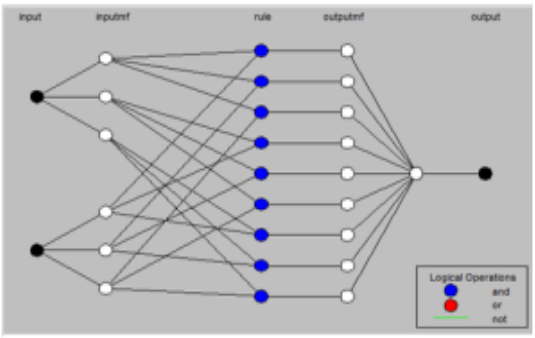


Fig 4. Structure of ANFIS Controller

supply voltages (Vsa ,Vsb ,Vsc) , load currents (ILa , ILb , ILc) and DC link voltages Vdc are sensed. Later load currents are converted from abc frame to pq frame using Clarke transformations as shown in Eqn.(2.5) .Voltages (vά and vβ) and currents (iά and iβ) are obtained from corresponding a–b–c frame components by using

$$\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{1}{2} & \frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_{La} \\ I_{Lb} \\ I_{Lc} \end{bmatrix} \tag{2.3}$$

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \tag{2.4}$$

$$\begin{bmatrix} I_\alpha' \\ I_\beta' \end{bmatrix} = \frac{1}{(V_\alpha)^2 + (V_\beta)^2} \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} -p \\ -q \end{bmatrix} \tag{2.5}$$

By using inverse Clarke transformation a',b',c' components are obtained using 2.4 ,2.5 and 2.6 equations.

$$\begin{bmatrix} I_a' \\ I_b' \\ I_c' \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_\alpha' \\ I_\beta' \end{bmatrix} \qquad (2.6)$$

Similarly Using the Clarke transformation we can obtain Vdq and idq Components. By using These Vdq , idq and I'dq components we will get V'dq using Equations 2.7 and 2.8.

$$V'_d = -(i'_d - i_d)K_p\left(\frac{1+T_{is}}{T_{is}}\right) + wL_f i_q + v_d \qquad (2.7)$$

$$V'_q = -(i'_q - i_q)K_p\left(\frac{1+T_{is}}{T_{is}}\right) - wL_f i_d + v_q \qquad (2.8)$$

Using inverse Clark transformation 〖V^'〗_d and 〖V^'〗_q components can be transformed to V'abc by using Inverse Clarke transformation. using PWM technique these Reference Voltage signals V'abc generates gating pulses , DSAPF injects the currents at PCC to suppress the harmonics in current.

The purpose of LC is to filter out the current ripple caused by the power switches of the active inverter part. The value of the Lf can be designed by using equation 2.9

$$L_f \geq \frac{V_{DC}}{8 * f_s * \Delta i L_{cmax}} \qquad (2.9)$$

Where VDC is the DC-link voltage, fs is the switching frequency, L_cmax is the maximum allowed output current ripple value.

A. Adaptive Hysteresis Control

There are several types of PWM current control strategies among them adaptive hysteresis PWM current control strategy is more efficient in fast response and good current limiting capability for DSAPF [19]. Figure 6 shows the two level current controlled method of adaptive hysteresis current control. The current-scale method of execution shows a two-step structure. Figure 7 shows HCC implementation using S-R flip-flop circuits for three-stage conversion. The comparator output goes the input of flip-flop and the positive internal band limit output will go to the input (S).

Negative inner band limit output will go to reset the input (R) of flip-flop. The output of the controller is used to gate the power switches; Q Gates top switch and Q Gates low switch.

Using HCC controller gating pulses are generated based on the difference between reference and actual source currents. Based on gating pulses DSAPF injects the currents at PCC to suppress the harmonics in current and compensates the reactive power demanded.

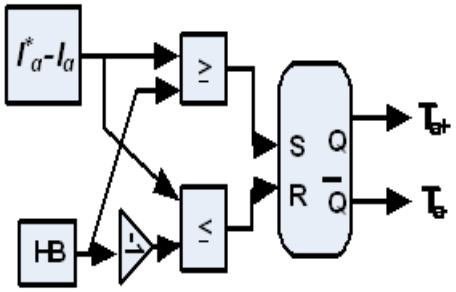


Fig 6 . Adaptive hysteresis band control

IV. Results and Discussion

Presented AHdq based DSAPF performance is studied in MATLAB / SIMUNLINK environment. Proposed system specifications and whose values are depicted in Table 1. Nonlinear loads are connected to line causes harmonics in source current and load places reactive power demand at PCC. To compensate these harmonics in the source current, equal and opposite currents have been injected by DSAPF.

Table1: System Parameters

S. No	Parameters	Ratings
1	Supply Voltage	3-phase , 230 V, 50 Hz
2	Load	Rl=10 Ω, Ll=30mH
3	DC link	Vdc = 750 V
4	Solar Cell	35V,7.5 A

The performance of source voltage and currents are analysed with the help of Modified dq control and Adaptive hysteresis current control methods under different supply voltage conditions and nonlinear loads. The Source current is free After t= 0.2 sec, due to the injection of compensating currents. Source current becomes sinusoidal. the performance evaluation is evaluated under different supply voltage conditions with nonlinear load. Here, the load current is supplied by source and PV fed to DSAPF. The different supply voltage cases are

Case A: Balanced source with balanced load
Case B: Balanced source with unbalanced load
Case C: Distorted source with balanced load
Case D: Distorted source with unbalanced load

using modified dq control and adaptive hysteresis control methods the performance of DC link voltage, power factor, source currents, compensating currents, load currents and current harmonic distortion were analysed.

A. DC Link:

The PV fed Adaptive Dynamic shunt active filter control technique maintains regulated DC voltage 750V across DC link capacitor. DC link voltage is as shown in Figure 7.

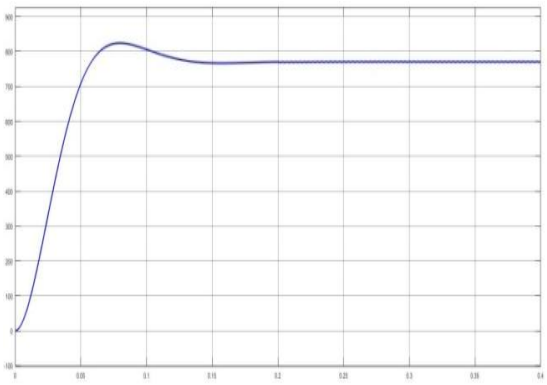
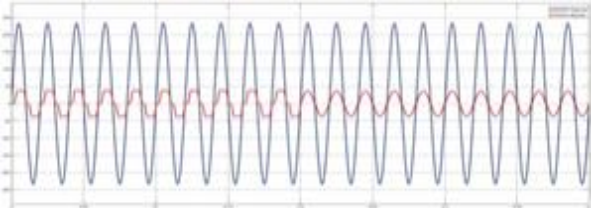


Fig 7: DC link voltage

B. Power factor improvement:

The Adaptive hysteresis DSAPF is switching on at T=0.2 sec. Before switching on time there is a current lag behind the voltage there is a considerable deviation between them. After T=0.2 sec the Adaptive hysteresis DSAPF switching on at PCC, due to compensation of reactive component, both currents and voltages are in phase ,it makes the power factor close to unity. The performance of phase voltage with respect to phase current by using modified dq control and Adaptive hysteresis control methods for different source voltage conditions as shown in figures.



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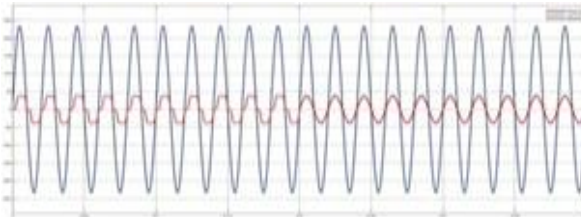

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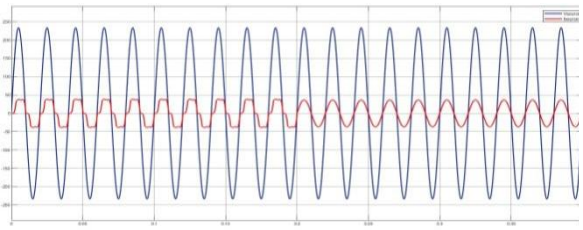

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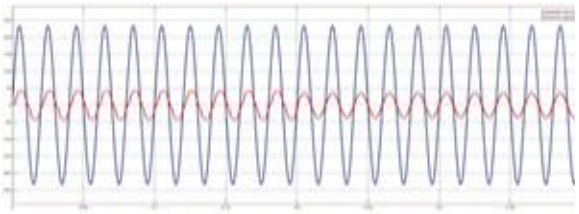

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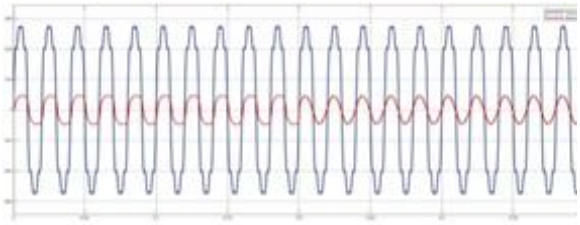

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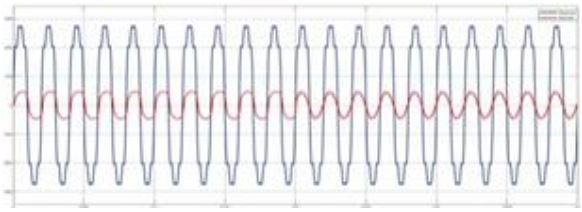

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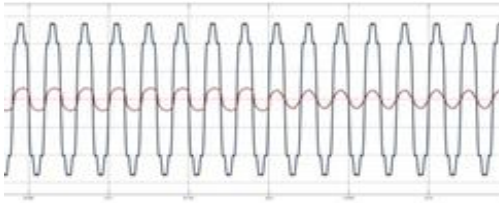

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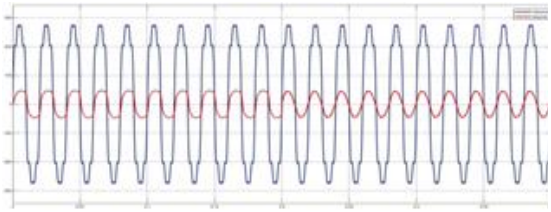

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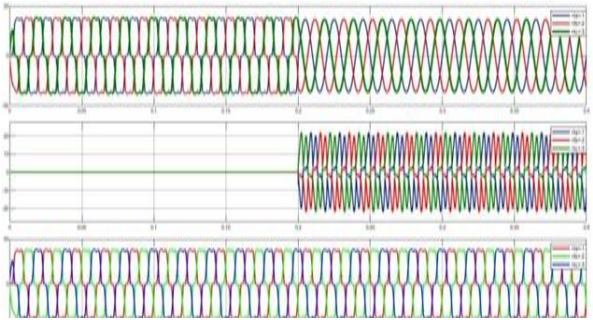
Fig 8: simulation results of phase voltage and current of phase A under different source voltage conditions(i) Source voltage under Balanced load with Modified dq Controller (ii) Source voltage and current under Balanced load with Adaptive HCC controller (iii) Source voltage and current under unbalanced load with Modified dq controller (iv) Source voltage and current under unbalanced load with Adaptive HCC controller (v) distorted Source voltage under balanced load with Modified dq controller (vi) distorted Source voltage and under unbalanced load with Adaptive HCC controller (vii) distorted Source voltage under unbalanced load with Modified dq controller (vi) distorted Source voltage under unbalanced load with Adaptive HCC controller

The performance of proposed controllers maintain almost unity power factor at T=0.2 secs under different source voltages with balanced and unbalanced loads. Under balanced loads modified dq control shows better results and under distorted un balanced loads Adaptive hysteresis controller gives better results. Source current at Phase A with phase voltage as shown in above figures.

Grid currents, compensating currents at PCC and load currents are illustrated in below figure. at T=0.2 sec the proposed controller injects the reactive compensating currents it suppress the current harmonics and makes source current is free from harmonics.



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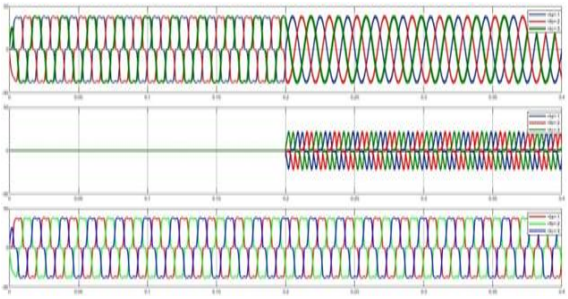

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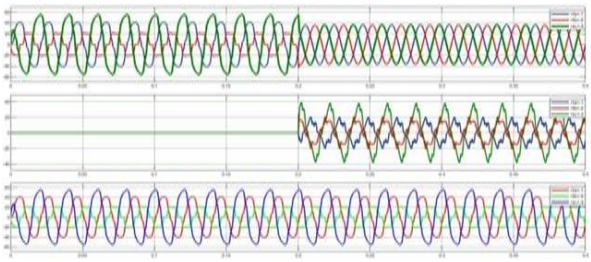

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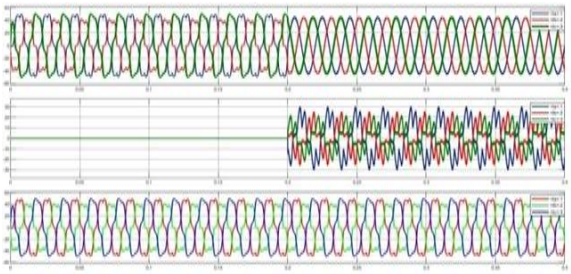

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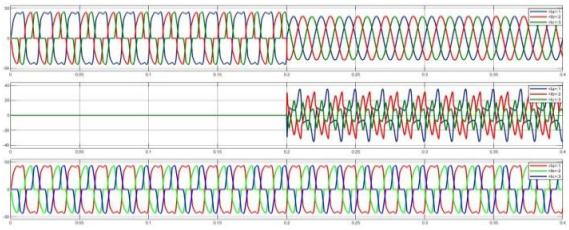

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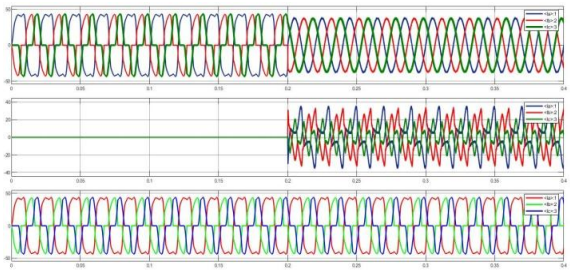

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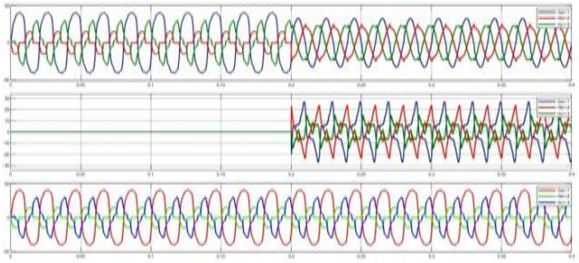

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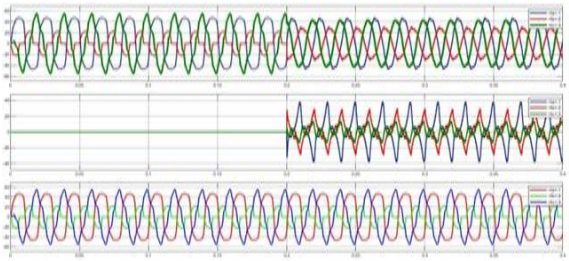

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Fig 9: simulation results of phase current ,Compensation current and and load current of phase A under different source voltage conditions (i) Source voltage under Balanced load with Modified dq Controller (ii) Source voltage and current under Balanced load with Adaptive HCC controller (iii) Source voltage and current under unbalanced load with Modified dq controller (iv) Source voltage and current under unbalanced load with Adaptive HCC controller (v) distorted Source voltage under balanced load with Modified dq controller (vi) distorted Source voltage and under unbalanced load with Adaptive HCC controller (vii) distorted Source voltage under unbalanced load with Modified dq controller (vi) distorted Source voltage under unbalanced load with Adaptive HCC controller.

C. Source Current Harmonics under different Source Voltage conditions:

The current harmonic reduction using modified dq control and adaptive hysteresis

controller is studied under different source voltages

Case1: The % THD of source current without DSAPF under balanced load shown in Figure 10 (i).Supply current % THD is higher value because of Nonlinear load.

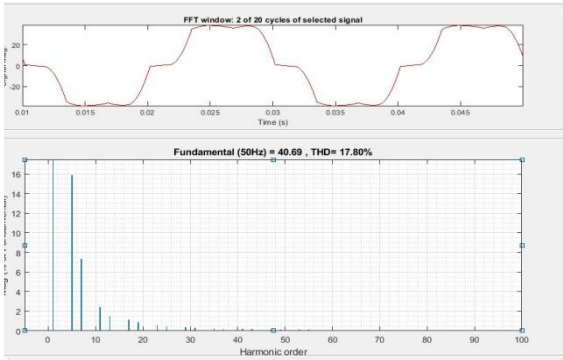
DSAPF is integrated to PCC at T = 0.2 sec. Post T = 0.2 sec, % THD of source current with Mdq controlled DSAPF is presented in Figure 10(ii).

DSAPF is integrated to PCC at T = 0.2 sec. Post T = 0.2 sec, % THD of source current with AHdq controlled DSAPF is presented in Figure 10(iii).

Case2: The % THD of source current with DSAPF under unbalanced load , DSAPF is integrated at T=o.2sec. Post T = 0.2 sec, % THD of source current with Mdq controlled DSAPF is presented in Figure 10(iv). The % THD of source current with AHdq controlled DSAPF is presented in Figure 10(v).

Case3: The % THD of source current with DSAPF under distorted source with balanced load , DSAPF is integrated at T=o.2sec. Post T = 0.2 sec, % THD of source current with Mdq controlled DSAPF is presented in Figure 10(vi). The % THD of source current with AHdq controlled DSAPF is presented in Figure 10(vii).

Case4: The % THD of source current with DSAPF under distorted source with unbalanced load , DSAPF is integrated at T=o.2sec. Post T = 0.2 sec, % THD of source current with Mdq controlled DSAPF is presented in Figure 10(viii). The % THD of source current with AHdq controlled DSAPF is presented in Figure 10(ix).



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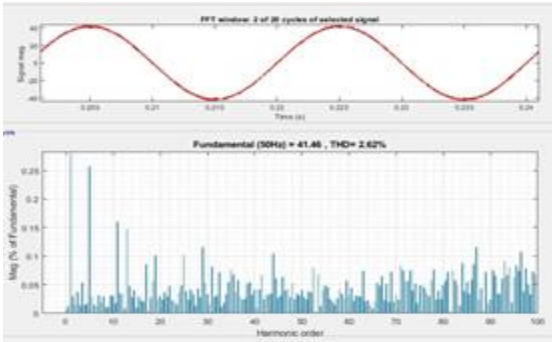

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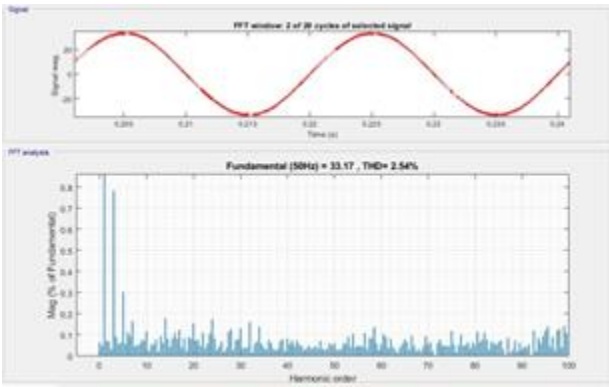

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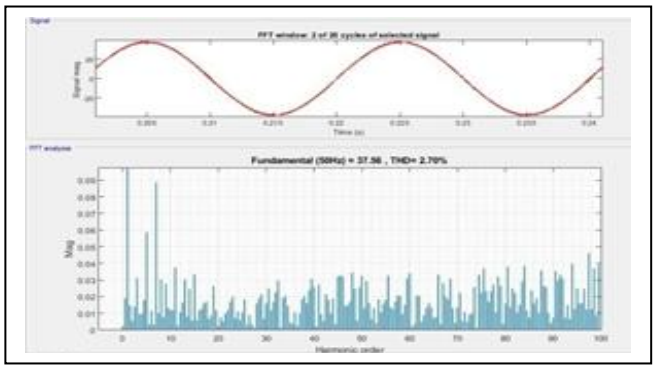

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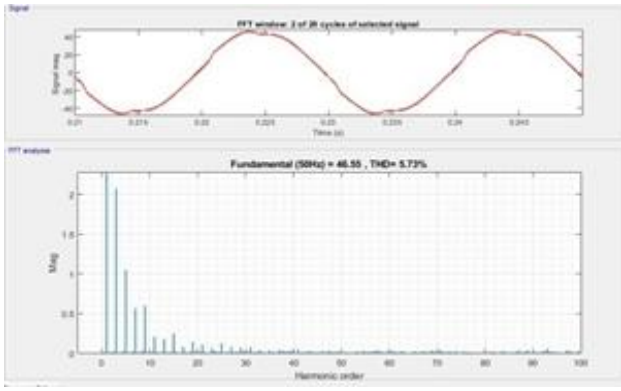

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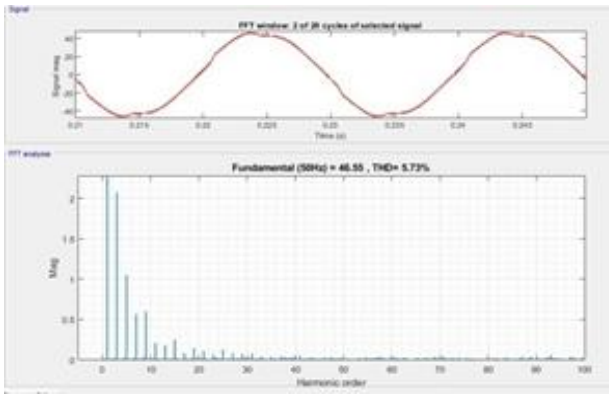

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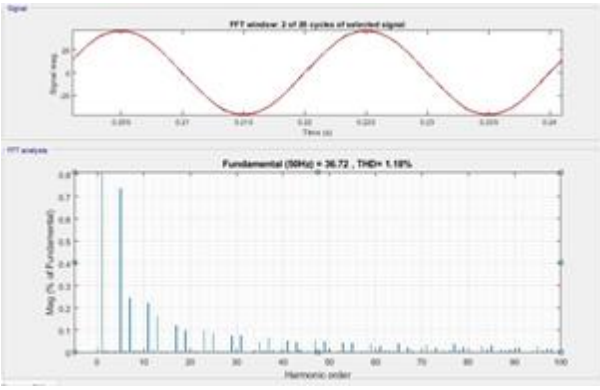

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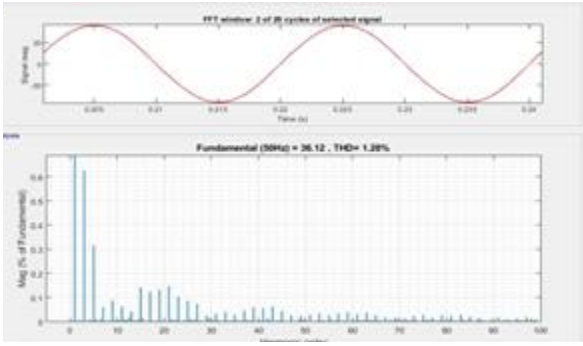

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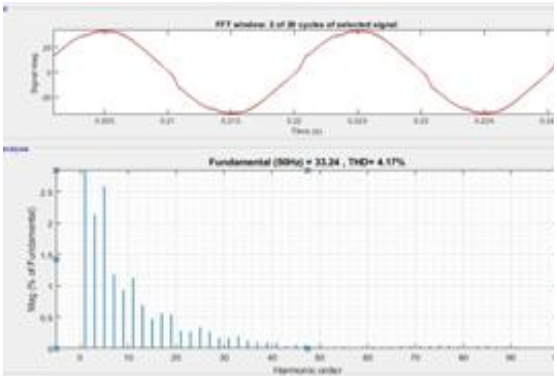

(ix)

Fig 10: simulation results of %THD current of phase A under different source voltage conditions (i) Source voltage under Balanced load with without Controller (ii) Source voltage under Balanced load with Modified dq Controller (iii) Source voltage and current under Balanced load with Adaptive HCC controller (iv) Source voltage and current under unbalanced load with Modified dq controller (v) Source voltage and current under unbalanced load with Adaptive HCC controller (vi) distorted Source voltage under balanced load with Modified dq controller (vii) distorted Source voltage and under unbalanced load with Adaptive HCC controller (viii) distorted Source voltage under unbalanced load with Modified dq controller (ix) distorted Source voltage under unbalanced load with Adaptive HCC controller

Table2: %THD current

Different cases of source and loads	% Current THD		
	With out filter	With Mdq-PI	With Mdq-HCC
A: With Bal source balanced loads	23.70	2.43	1.38
B: With Bal source un Balanced loads	25.8	2.54	1.29
C: With Distorted source balanced loads	24.50	2.43	1.15
D: With Distorted source unbalanced loads	28.6	7.86	5.72

The above Table 2 presents performance comparison of Mdq based DSAPF and AHdq based DSAPF. Both the methods effectively reduce the % THD value with in IEEE 1549 standards. it can be concluded that AHdq controlled DSAPF effectively alleviates the % THD .

V. CONCLUSION

In this paper performance of Adaptive Hysteresis based modified dq (AHdq) controller is studied for alleviating current harmonics and compensation of reactive power. The Proposed Controller is more effective in reducing the harmonic distortions in source current. When AHdq-DSAPF is integrated with the grid, power factor of the system is improved even under operating with nonlinear loads. Congruous design presented in this paper eliminates the additional power conditioning devices for renewable source integration. Endurance performance of Adaptive hysteresis based dq controller based dynamic shunt APF effectively reduce the supply current harmonics and brings the power factor to unity.

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