International Journal of Advance and Innovative Research
Volume 10, Issue 1: January - March 2023
ISSN 2394 - 7780

5 LEVEL CASCADED INVERTER BASED D-STATCOM

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ABSTRACT

5 level cascaded inverter based D-STATCOM for harmonic and reactive power compensation, provides a simple three-step LPF-BPF based fundamental active current extractor system. The proposed LPF-BPF fundamental current extractor offers an instantaneous value for the fundamental active component of load current, which ensures that the source current is sinusoidal and the supply power factor (UPF) is maintained. The proposed algorithm extracts the fundamental active component of load current with THD less than 5% and maintains unity power factor at the supply end when the supply voltage is distorted. The goal of this paper is to look at the design, analysis, and control of various cascaded multi-level inverter topologies for single phase static VAR compensator (STATCOM) applications

Keywords— Cascaded, Inverter, Fundamental, Active, D-Statcom

INTRODUCTION (*HEADING 1*)

The Smart City Mission is receiving a lot of attention from the Indian government. For a city to be transformed into a smart city,ten fundamental infrastructural elements are required. Three key electrical engineering elements are assured electric supply, sustainable environment and Efficient urban mobility and urban transport.

The four areas under electrical engineering are renewable energy technology Control of Solar and Wind Energy Systems, Power Quality Enhancement, Distributed Generation and Electric Vehicle to Grid interface(V2G). Utility and customer-side disturbances are the primary causes of terminal voltage fluctuation, transients, and wave form distortions on the distribution system. Power quality engineers are becoming increasingly concerned about the quality of electrical power. Electronic switching devices, which are commonly included in new load equipment, may result in poor network voltage quality. Power electronics' wide spread use in the residential, commercial, industrial, and transportation sectors has resulted in everincreasing non-linear loads. Power quality difficulties (PQ) such as current and voltage distortions, power factor (PF) degradation, electromagnetic interference, voltage flicker, etc have resulted. The widespread usage of inductive loads, which require reactive power, exacerbates PQdifficulties. This causes further distribution system degradation and underutilization, as well as voltage sags and swells. The negative consequences of low PQ have led to the creation of power quality standards, such as IEEE-519-2014/IEC-61000 which when observed would minimize the adverse effects.While power electronics are responsible for the majority of PQ concerns, they are also responsible for the solution. Various custom power devices that can ensure compliance with PQ rules have been mentioned in the literature. The distributed static compensator (D-STATCOM) is one such device that may compensate for harmonic current and reactive power without requiring the supply to offer only the fundamental current at unity PF (UPF). D-STATCOM based on a 1/3-phase voltage source inverter has been documented in references [1] –[27].

For1-phaseFL-CHBI basedD-STATCOM, this work provides a simple LPF-BPF basic current extraction algorithm. To estimate the peak magnitude of the fundamental, the proposed LPF-BPFcurrent extraction technique first estimates the fundamental in-phase and quadrature components. Second, for the development to unitv vector template(UVT), the same technique is repeated for the supply voltage, guaranteeing that the algorithm functions well even with a distorted supply. Finally, the instantaneous value of the fundamental active component of load current is computed based on the two steps. The control method ensures that the grid only supplies resulting source current with total harmonic distortion (THD) below 5% and UPF at the supply end. In addition, voltage balancing is included for CHBI. Under dynamic and state settings for undistorted and distorted power supplies, the functioning of the 1-phase FL-CHBI based D-STATCOM with the suggested LPF-BPF fundamental current extractor is investigated. For high-power applications, D-STATCOM, which consists of cascading traditional multi-level/two-level inverters, is an appealing solution. The architecture consists of standard multilevel/two-level inverters coupled in cascade via a three-phase transformer's open-end windings. In high- power drives ,such topologies are common. One of the advantages of this design is that the number of levels in the output voltage wave form can be increased by maintaining a symmetric voltages at the inverters ' dclinks. This enhances the quality of the power. As a result,compared to traditional multilevel inverters, overall control is straight forward.

2. THEORY AND FORMULA

1.1 CONTROL SCHEME AND MODULATION TECHNIQUE OF D-STATCOM

2.1.1 LPF-BPF Fundamental Extractor and calculations:

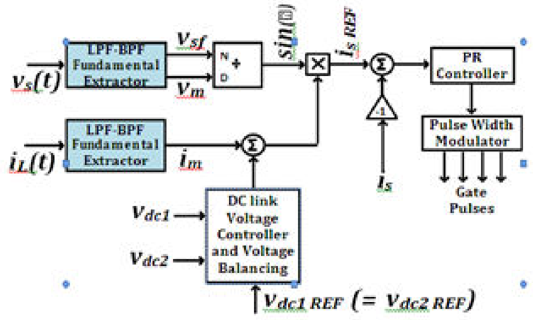


Figure4.shows the block diagram of the control scheme

Let the distorted $vs(t)$ and $iL(t)$ be defined as in equations (1) and (2), where $Vm1$ and VmK are the peak voltages of fundamental and Kth harmonic components, $Im1$ and ImK are the peak voltages of fundamental and Kth harmonic components, φ and φK are the angle by which fundamental and harmonic components of iL lags behind the voltage, and t is time.

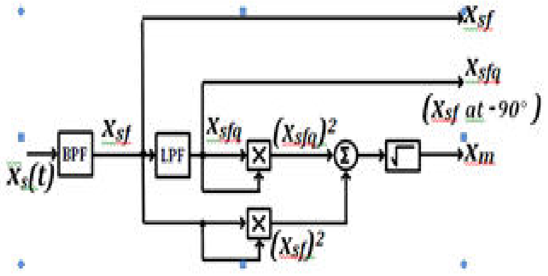


Figure5.LPF-BPFFundamentalExtractor Block

The proposed LPF-BPF fundamental active current extractor combines the operation of PLL and fundamental current estimator for the extraction of fundamental active component of load current. Fig. 4 shows 4 shows the schematic diagram of LPF-BPF fundamental current extractor.

$$(t) = V_{m1}\sin(\theta) + \textstyle\sum_{k=2}^{\infty} V_{mk}\sin(k\theta) \qquad (1)$$

$$(t) = I_{m1}\sin(\theta-\varphi) + \textstyle\sum_{k=2}^{\infty} I_{mk}\sin(k\theta-\varphi_k) \qquad (2)$$

In Step-1, employs fundamental component extraction for the determination of peak magnitude of fundamental load current. In S- domain the output of II-order BPF, (S), while processing (S), is given as in equation (3), where $G(S)$ is transfer function of BPF, B is the passing band and ωo is the centre frequency. From equation (4), it is clear that the output of BPF in time domain, (t),is equal to the fundament component of load current, $iLf(t)$, and consists of the $iLfp(t)$ and $iLfq(t)$.

$$I_{\_p}(s) = G_{BPF}(s)I_L(s) = B\frac{s}{S^{2+Bs+\omega_0^2}}I_L(s) = I_{Lf}(s) \qquad (3)$$

$$(t) = i_L(t) = i_{Lfp}(t) + i_{Lfq}(t) = I_{m1}\sin(\theta-\varphi) \qquad (4)$$

As BPF cannot separate (t) and $iLf(t)$, $ip(t)$[= $iLf(t)$] is passed through LPF to get $iq(t)$.(S) is further processed by LPF to determine the quadrature component, (S), as in equation(5), where $GLPF(S)$ is transfer function of LPF, ωc is the cut-off frequency, μ is the coefficient of damping. From equation (6), it is clear that the output of LPF in time domain, (t), is in quadrature with (t). Based on equations (5)-(6), the peak magnitude is determined as in equation

$$I_q(s) = G_{LPF}(s)I_p(s) = 1.41\frac{\omega_c^2}{S^{2+2\mu s+\omega_0^2}}I_p(s) = I_q(s) \qquad (5)$$

$$(t) = I_{m1}\sin(\theta - \varphi - 90°) \quad (6)$$

$$I_{m1} = \sqrt{[i_p(t)]^2 + [i_q(t)]^2} \quad (7)$$

In Step-2,the fundamental component extractor is employed for the estimating $Vm1$ and the fundamental in-phase component of (t), vsp (t). The use of fundamental component extractor ensures that

UTV having only the fundamental frequency component

is generated even under distorted supply conditions.

First (t) is determined by BPF, based on which the

fundamental quadrature component of (t), $vsq(t)$ is

obtained through LPF. With thus obtained vsp (t) and

vsq (t), $Vm1$ is determined as in equation (8). Finally,

generated UTV is given by equation (9)

$$V_{m1} = \sqrt{[v_{sp}(t)]^2 + [v_{sq}(t)]^2} \quad (8)$$

$$UTV = V_{m1}(t) = V_{m1}sin(\theta) = \sin(\theta) \quad (9)$$

Lastly, Step-3 is employed for the separation of (t)

and $iLf(t)$ components of $iLf(t)$. Based on equations (7)

and (9), (t) is determined as in equation (10). Use of thus

obtained (t) acts as $iREF$ (t), ensures the desired

D-STATCOM operation. To accommodate the dc-link voltage regulation and cell voltage balancing, the modified $iREF$ (t) is given by equation (11).

$$i_{(t)} = UTVI_{m1} \quad (10)$$

$$i_{REF}(t) = UTV(I_{m1} + i_{dcREF}(t)) \quad (11)$$

3. RESULTS & DISCUSSIONS

1.1 PERFORMANCEANALYSIS

Table1.%THD for different modulating index and different level of inverter

% THD of Current in 5-Level Cascaded Inverter			
M.I	**IPD**	**POD**	**APOD**
0.7	2.16	2.16	2.16
0.85	1.85	1.85	1.85
1	1.43	1.43	1.43

% THD Current in 7-Level Cascaded Inverter		
IPD	**POD**	**APOD**
1.64	1.61	1.64
1.44	1.33	1.36
1.15	1.03	1.03

% THD of Current in 9-Level Cascaded Inverter		
IPD	**POD**	**APOD**
1.14	1.03	1.02
1.16	1.09	1.10
0.84	0.79	0.79

Table2.Switching losses for different Modulating techniques and different level of inverter

Modulating Techniques	5-Level CMLI Switching loss	7-Level CMLI Switching loss	9-Level CMLI Switching loss
IPD	0.9638	1.2247	1.6348
POD	0.9606	1.1747	1.6175
APOD	0.9631	1.1847	1.6275

1.2 SIMULATION RESULTS

5-level,7-level and 9-level voltage source inverters have been implemented using Sinusoidal pulse width modulation. Results are shown in figure 9 below

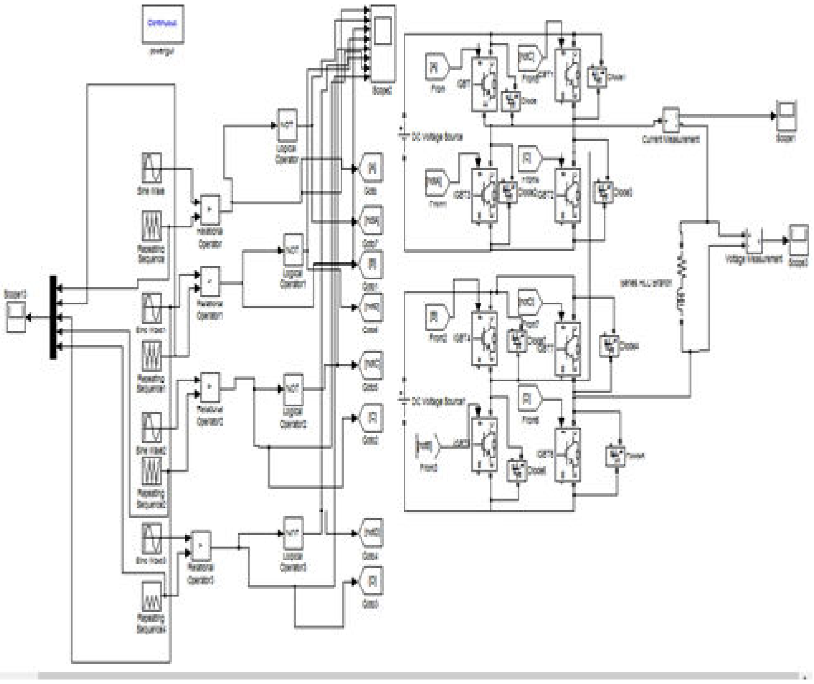


Fig9. 5-level,7-level and 9-level voltage source inverters

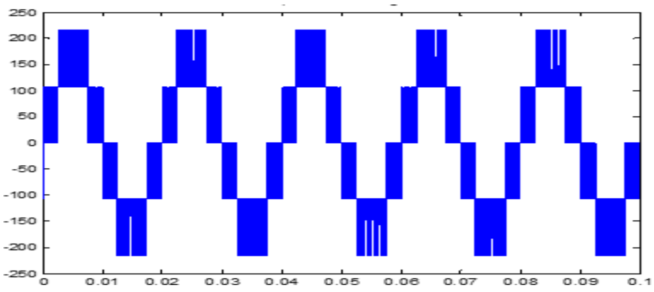


Fig.10. Voltage of 5-Level CMLI

Figure 10.shows the 5-Level voltage waveform of cascaded multi level inverter and 5-level of voltage is generated using two same value of the voltage sources. 110 V of dc sources are generate5-level of voltage.

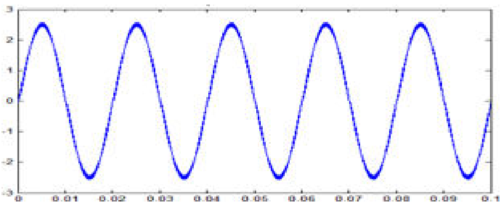


Figure11. Current of 5-Level CMLI

Figure 11.shows the current waveform of output inverter. It is purely sinusoidal having THD of 2.16 % , the 0.7 modulating index. THD will decrease with increase in the modulating index.

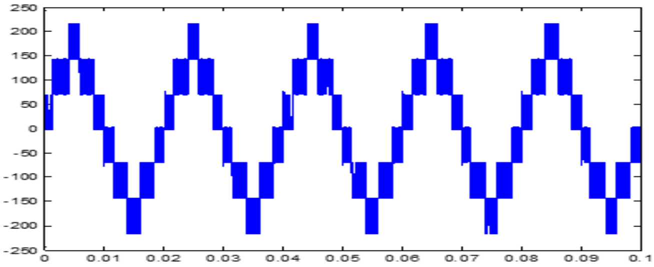


Figure12.Voltageof7-LevelCMLI

Figure 12.shows the 7-Level voltage waveform of cascaded multi level inverter.7-level of voltage is generated using two different values of voltage sources. Like 145 V and 75 V of dc sources are generate 7-level of voltage.

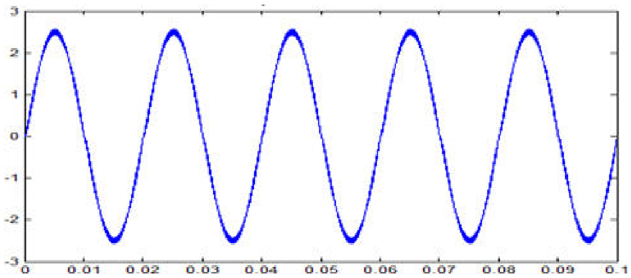


Figure13.Current of 7-Level CMLI

Figure 13.shows the current waveform of output inverter. It is purely sinusoidal having THD of 1.64 % with 0.7 modulating index. THD will decrease with increase the modulating index.

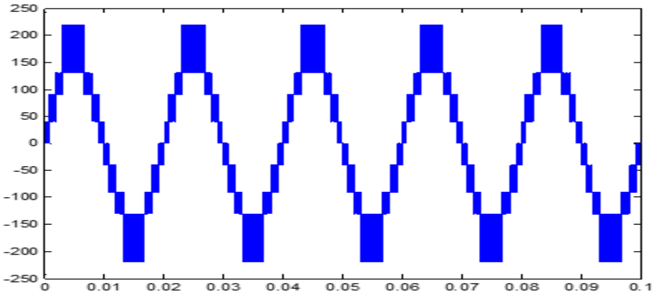


Figure14.Voltageof9-level CMLI

Figure14.shows the 9-Level voltage waveform of cascaded multi level inverter.9-level of voltage is generated using two different values of voltage sources. Like 90V and 130V of dc sources are generate 5-level of voltage.

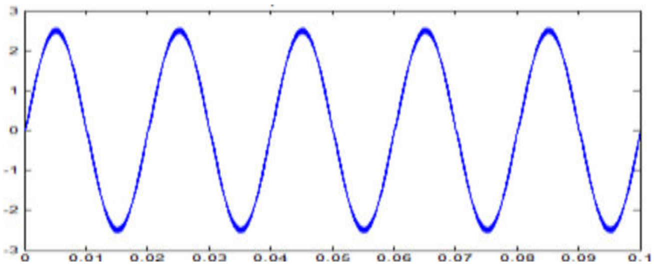


Figure15.Current of9-LevelCMLI

Figure 15.shows the current waveform of output inverter. It is purely sinusoidal having THD of 1.16% with 0.7 modulating index. THD will decrease with increase in the modulating index.

Figure 15.shows the current waveform of output inverter. It is purely sinusoidal having THD of 1.16%

With 0.7 modulating index. THD will decrease with increase in the modulating index

2) Simulations are carried out in MATLAB software for single phase FL-CHBI based D-STATCOM with the proposed control scheme. The system parameters are: Gridvoltage: 84.85V, 50Hz rms gridvoltage, coupling inductor impedance of : (1+j 0.0002), dc-linkcapacitors: 1100microF, lineimpedance:(1+j0.001) .Load-1:1-phase

uncontrolled rectifier with resistive and inductive load (50,100mH) and Load-2:1-phase uncontrolled rectifier with resistive and inductive load (50,200mH) and 1-phase uncontrolled rectifier with resistive and inductive load (50,100mH). The load current (L)is found to have a peak value of 1.86A at 39.99 %.THD under Load-1. Load-2, on the other hand, pull siL with a peak value of 3.36A at 22.73%THD. The simulation studies are carried out for the following cases of supply and load conditions are;

Undistorted supply voltage with steady state load.

Fig (a-b-c-d) shows

VPCC is sinusoidal with the RMS value of 84.85Vand THD of 1.0%.

iL is highly distorted with the peak value of 1.83A and THD of 27.5%.

iL having the peak magnitude of 0.43A and 0.25A.

iL having the peak and RMS values of 1.95A and1.32A, sinusoidal with THD of 2.4%.

In phase with Vpcc with the PFof 0.9997.Compensating current peak value of 1.44A.

The two most dominant harmonics 5thand7th the peak magnitude of 0.43A and 0.24A.

Maintained at an average values of 99.2V and 100.2V.With the respective peak-to-peak ripple of 0.3V and 0.1V. The determined by the proposed fundamental active current extractor is 2.05A.

With the peak to peak ripple of 0.05A

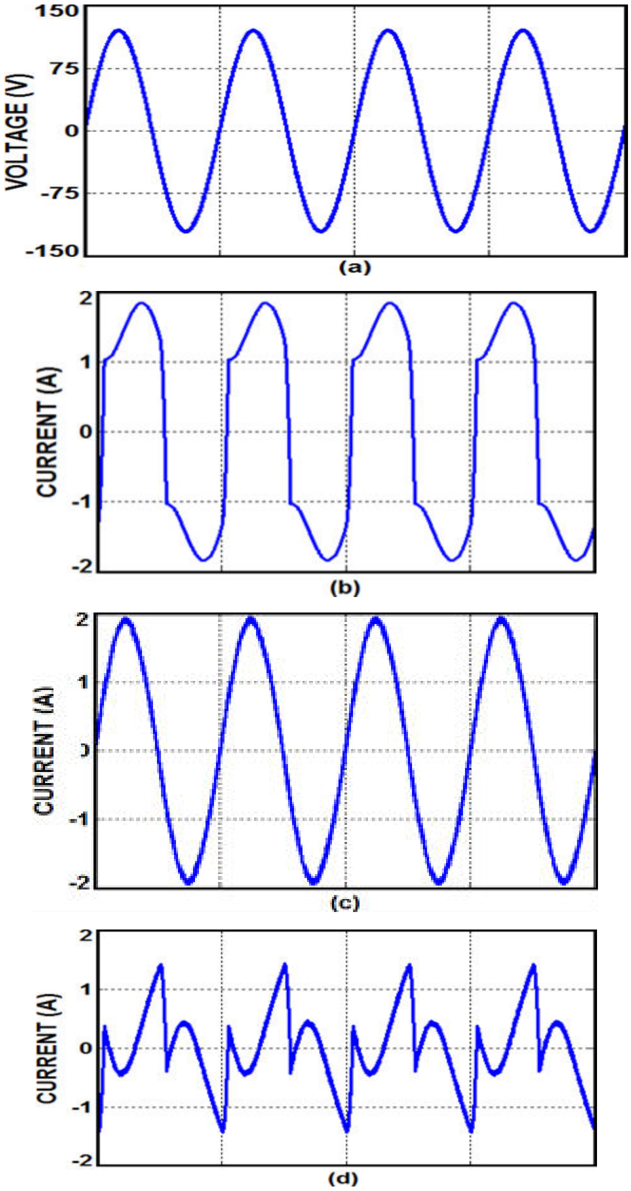


Fig 16. Undistorted supply voltage with steady state load

Undistorted supply voltage with dynamic load condition

Fig. (g-h-j-i) depicts the performance of the 1-phase FL-CHBI based D-STATCOM with LPF-BPF fundamental active current extractor under thedynamic load change. Load-1 is connected to the system. With a change in load from Load–ItoLoad –IIat4s , the peak magnitude is increases from 1.83A to3.3A. themaximum peak value of 3.42A under dynamic state. THD of the two different load is less than5%. The step increase in load causes drop in Vdc1 andVdc2 drop to a minimum value of 97.8V and 97.5Vduring the Dynamic state.

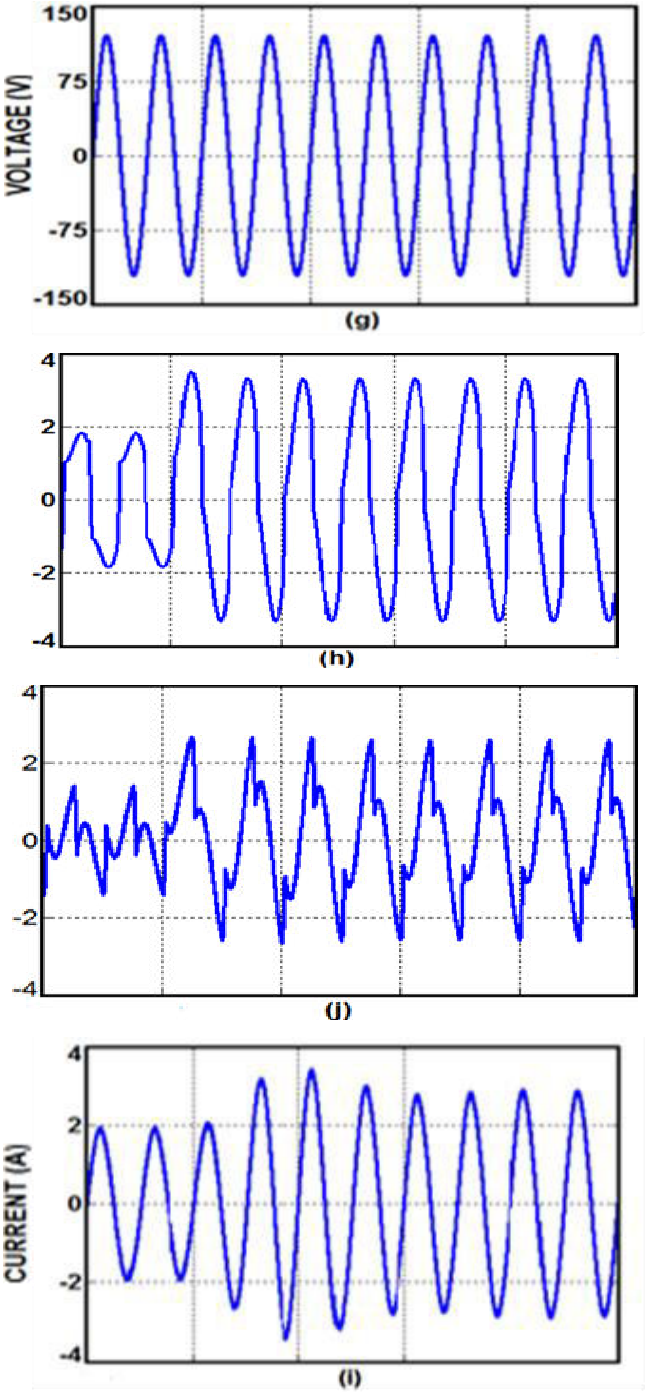


Fig17.Undistorted supply voltage with dynamic load condition

Distorted supply voltage with steady state load condition:

The distorted supply voltage considered in this study is given as

∞

$(t)=\sum vmn\sin(n\omega t.)$

$n=1$

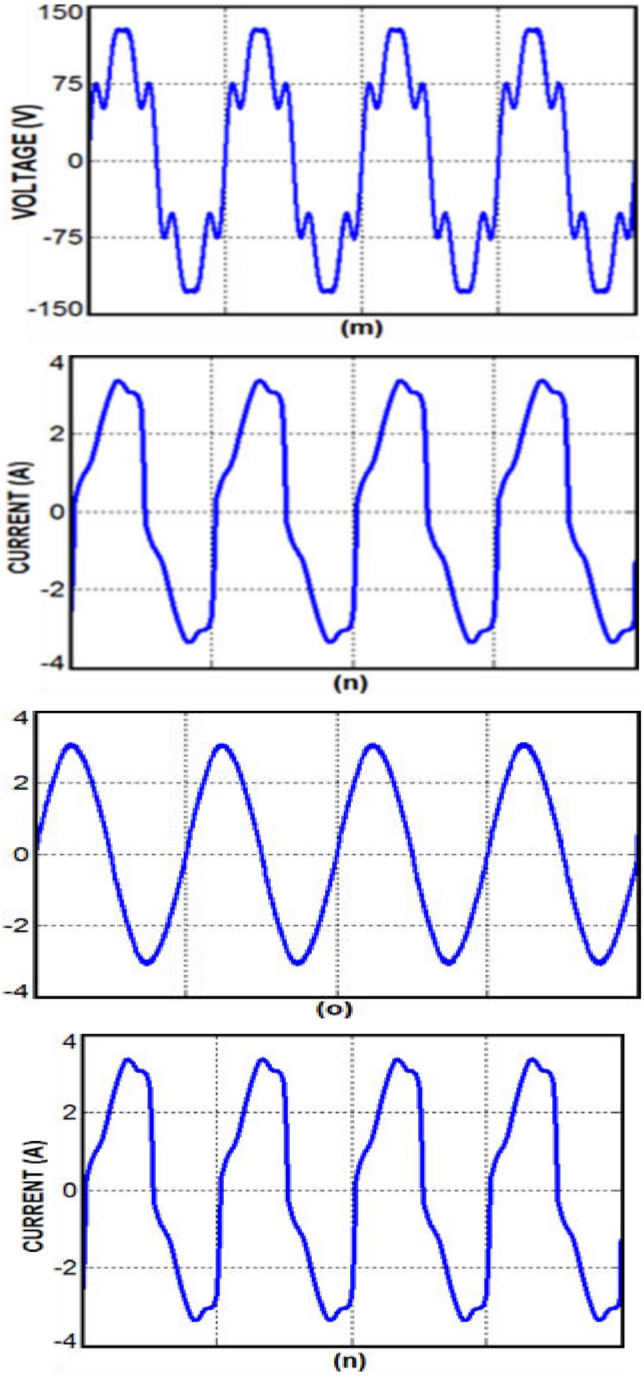
Fig. (m-n-o-p) illustrates the steady state performance of 1-phase FL-CHBI based D-STATCOM with LPF-BPF fundamental active current extractor under distorted $vPCC$. Distorted $vPCC$has the peak value of 129V and THD of 24.5%.

The two most dominant harmonic are 5th and 7th peak magnitude of 24Vand17V.

Resulting iL and is highly Distorted with the peak value of 3.4A and THD of 22.6%.

The two most dominant harmonics are having The peak magnitudes of 0.51 and 0.4. even with the distorted supply, the D-STATCOM provides effective compensations of that, with The peak value of 3.1A, has THD of 2.3%, and is in phase with Vpcc. This results in Supply end PF being maintained at 0.9997.It has The peak value of 2.7A.with The 5th and7th being the most two dominant harmonics having a peak magnitudes of 0.52A and0.41A.Respectively, Vdc1and Vdc2 are regulated at an average value of 99.7V and100Vwith the peak-to-peak rippleof 0.4V and 0.02V,

Even under the distorted supply, the proposed fundamental active current extractor effectively determines that im1has an average value of3.4Aandpeak-to-peak rippleof0.08A.



(m)

(n)

(o)

(n)

Fig18.Distortedsupplyvoltagewithsteadystateloadcondition

CONCLUSION

The proposed LPF-BPF fundamental active current extractor algorithm has been implemented in PSIM simulation package for the control of 1- phase FL-CHBI based D-STATCOM for demonstrating its effectiveness in mitigating PQ issues for the distribution system, thereby facilitating sinusoidal source currents and UPF at supply end. The control system ensures that only the extracted fundamental active component of load current is fed by the source, implying that the D-STATCOM provides harmonic current and reactive power compensation. This simulation results validate the theory by demonstrating that the source currents are the fundamental active component of load current, drawn at UPF and having THD well below the 5% limit set by the IEEE standard 519. Moreover, voltage balancing for the CHBI is also incorporated. The performance of the 1-phase FL-CHBI based D-STATCOM with the proposed algorithm was found to be satisfactory under the dynamic load change and even under distorted supply conditions.

ACKNOWLEDGMENT *(HEADING 5)*

We acknowledge the resources made available in support of the ME part III-IV research work carried out by Mr Ravin Patel in the department of electrical Engineering, Faculty of Technology & Engineering, The Maharaja Sayajirao University Of Baroda, Vadodara.

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