Direct Power Control Of Three Phase Pwm Rectifier Based On Duty Cylce Approach

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***Abstract*—The DPC (Direct Power Control) with switching table control and variable switching frequency produces severe irregular ripples. In duty cycle concept based DPC (Direct Power Control) of PWM rectifiers the application of active voltage vector for fractional period and the rest period by the null vector not only makes it line side inductance independent of the circuit and is very simple to implement. In the simulation it is observed that the level of distortion as well as regulation of the DC link voltage with control of power factor improves the overall performance. The duty cycle concept based DPC PWM methodology is comprehensively analysed for three phase rectifiers. The performance analysis is carried out in MATLAB/Simulink environment, the results of simulations indicate the effectiveness in obtaining UP) (Unity power factor) and constant dc link voltage control. Sinusoidal input grid currents are obtained with considerably reduced power ripples.**

Keywords— Direct power control, pulse width modulation, duty cycle, dc link control, instantaneous active and reactive power, unity power factor

I. Introduction

The application of three phase rectifiers have tremendously increased in the areas like adjustable speed drives, FACTS, renewable energy systems etc. There are various models for power control of PWM rectifier like VOC, DPC, VF-VOC and VF-DPC. Voltage oriented based control decomposes grid currents into active and reactive power components separately which through PI controllers are fed through modulator to synthesize voltage vectors. Fine tuning of PI is required to achieve steady and dynamic response.

In DPC for achieving satisfactory performance the switching frequency required is very high, which adds up to the hardware burden. Major work has been done to tackle this problem such as SVM-based DPC, predictive control, fuzzy logic control and deadbeat control etc. But these methods further increased the complexity and computational burden. To address the problem several techniques with new switching tables were proposed. But they tried to incorporate accuracy and efficiency by eliminating ac voltage sensors, which reduced the overall system robustness.

Conclusively the duty cycle concept based DPC that is analysed here does not focus on effectiveness of switching tables rather it focuses on improving steady performance. The parameter being selected for this is duty cycle of the voltage vectors. The concept of duty cycle control is to select the fraction of time for which the voltage vector will be applied. The existing duty cycle methods were parameter dependent, which was again contributing to decreasing robustness and increasing complexity. The improved method is kept simple by eliminating the requirement of system parameters. Simulation results prove that the new duty cycle concept based DPC has high performance.

DPC is high performance instantaneous power control theory basically similar to DTC in motor drives. It directly selects the desired grid voltage vector from predefined switching table according to the grid voltage position or virtual flux position and the errors between the reference and feedback powers are calculated. Conventional DPC has a drawback of high power ripples and variable switching frequency. The duty cycle concept based DPC introduces the concept of fractional control by active vectors over the allocated period improves the performance of the rectifier by making it independent of line inductances thus robustness is achieved and ripples in power are also reduced with almost unity power factor operation.

Unique features offered by this duty cycle concept based DPC are:

- Fixed and low switching frequency.
- Sampling frequency for digital implementation is low.
- Parameter independent thus robust.
- Simple & easy control with only two voltage vectors.

II. PRINCIPLE OF DPC IN THREE PHASE PWM RECTIFIER

The topology as seen from the fig.1 which is two level can be mathematically modelled into two phase stationary reference (α β) frame and with R and L as equivalent series resistance and choke.

The Direct Power Control (DPC) is based on the instantaneous active and reactive power control loop. There are no internal current control loop and no PWM modulator block. The switching states are determined with a switching table based on the instantaneous errors between the commanded and estimated values of active and reactive power.

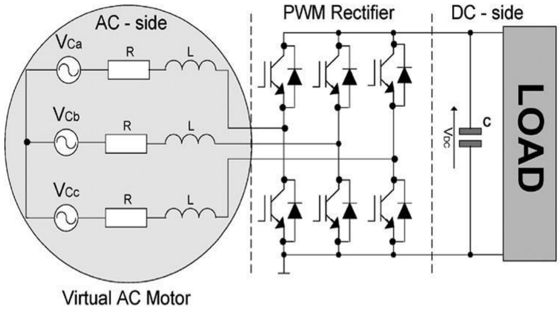


Fig.1 Three phase rectifier topology [1]

Fig.2 shows the conventional classical configuration of DPC where the instantaneous active and reactive powers are the controlled variables, this method is based on switching table for selecting the desired voltage vector. The PI controller needs fine tuning and the power ripples along with harmonic distortion in the input side cannot be filtered out easily with this basic configuration.

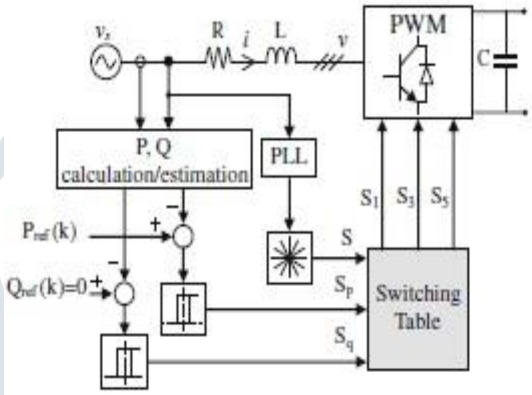


Fig.2 Classical Configuration of DPC with PLL

According to the switching table first time as used by Noguchi et al for the control scheme as depicted in fig.2. This method is based on selecting a voltage vector from lookup table, Table I, according to the errors of active and reactive powers as well as the angular position of the source voltage vector. The variable switching frequency introduces harmonic spectrum in AC line currents and thus the design of filters become very difficult. . In order to attenuate the harmonics and power ripples large value of sampling frequency and inductance should be selected this increases the cost , losses and reduces system dynamics. There have been many approaches to control these factors as virtual flux estimators but PI controller tuning is very complex and thus it becomes difficult to achieve high dynamic performance.

III. DIRECT POWER CONTROL WITH FRACTIONAL CONTROL

The duty cycle concept based direct power control method has advantage of:

- Simple algorithm for duty cycle determination
- Independent of line inductance parameter
- Operation at constant frequency simple filter design
- Low switching and sampling frequency

Calculations are fast and simplified

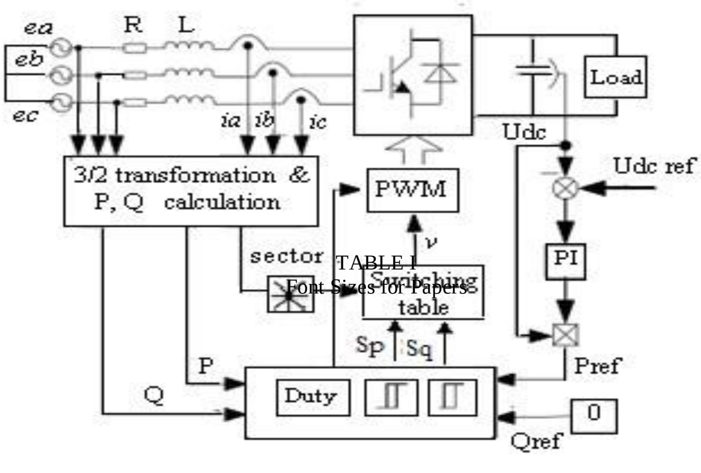


Fig.3 duty cycle concept based DPC [1]

The equation for grid voltage '*e*' can be written as:

$$e = Ri + L\frac{di}{dt} + v \qquad (1)$$

Where *v*, *e*, *i* represent rectifier voltage vector, grid voltage vector and grid current vector respectively.
Transforming the three-phase model to stationary (*α β)* frame, the complex power S for active power P and reactive power Q can be given as:
Complex power as per [1]

$$S = P + jQ = 1.5(i * e) \qquad (2)$$

Instantaneous active power

$$P = u\alpha\ i\alpha + u\beta\ i\beta \qquad (3)$$

Instantaneous reactive power

$$q = u\beta\ i\alpha - u\alpha\ i\beta \qquad (4)$$

The equation for grid voltage 'e' is:

$$e = |\ e|\ e^{j\omega t} \qquad (5)$$

Differentiating 'e' we get:

$$\frac{de}{dt} = j\omega|\ e|\ e^{j\omega t} = j\omega e \qquad (6)$$

Differentiating the grid current '*i'*:

$$\frac{di}{dt} = \frac{1}{L}(e - v - Ri) \qquad (7)$$

Now differentiating complex power:

$$\frac{dS}{dt} = \frac{1}{L}[1.5(|\ e|\ ^2 - v * e - (R - j\omega L)S] \qquad (8)$$

$$\frac{dP}{dt} = \frac{3}{2*L}[|\ e|\ - Re(v * e)] - \left(\frac{R}{L}\right)P - \omega q \qquad (9)$$

$$\frac{dQ}{dt} = -\frac{3}{2*L}(Im(v * e) - \left(\frac{R}{L}\right)Q + \omega p) \qquad (10)$$

The expressions can be further simplified as :

$$\frac{dP}{dt} = \frac{3}{2*L}|\ e|\ 2 - \left(\frac{V_{dc}}{L}\right)|\ e|\ \cos\left(\omega t - \frac{\pi(n-1)}{3}\right)\frac{R}{L}P \qquad (11)$$

$$\frac{dQ}{dt} = -\frac{3}{2*L}\left(\frac{V_{dc}}{L}\right)|\ e|\ \sin\left(\omega t - \frac{\pi(n-1)}{3}\right) + \omega p \qquad (12)$$

The power slopes can be calculated from eq. 9 and 10.The rectifier voltage vectors with 6 sector division are as shown below

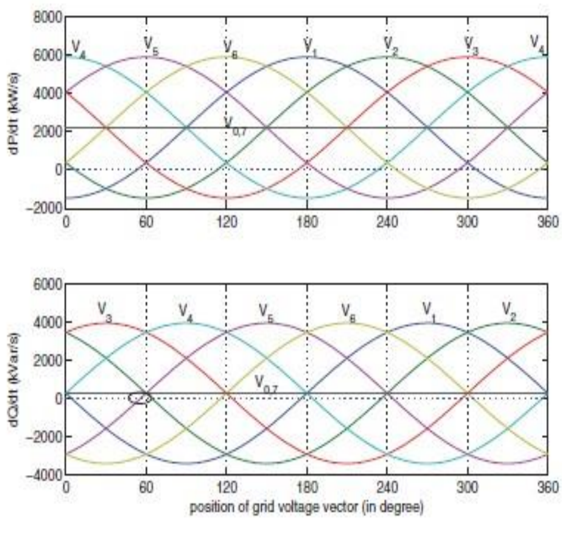


Fig.4 Slopes of active and reactive power vs. grid vector position for various rectifier voltage vectors (assuming p=900w and q=0) [1]

According to the influences of voltage vectors over active and reactive power slopes in any sector k can be obtained as shown in table 1.where 'k' is 't' cycling index .For controlling the active and reactive power simultaneously we can select specific set of vectors corresponding to incremental or decremental nature of P or Q .Based on the analysis of appropriate set of combinations of voltage vectors, it is noticeable that switching tables based on grid voltage vectors have some inherent drawbacks especially in wide power range. The effort to improve the selection of appropriate vector is done as per the following model. The 6 sectors on stationary reference frame and the rectifier voltage vectors are presented in fig.5.

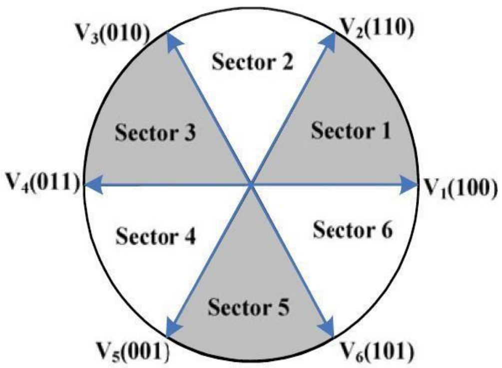


Fig.5 Rectifier voltage vectors and sector division of DPC [1]

For simultaneous control of both active and reactive power the Table I. can be summarized. It can be seen that there are more than two vectors to satisfy a change in power requirement. For example if both P and Q are increasing then V0,7 produces least variation on Q, small (first half sector) or medium (second half sector) variation on P.Vk+3 has the biggest influence on P and medium on Q. The influence of Vk+2 is moderate. Similarly for P increasing and Q decreasing there are insignificant differences between Vk-1 and Vk-2except that when transition from sector k to k+1, Vk-2 increases Q rather than decreasing with a value smaller than that caused by null vector.

Table I: Switching table for DPC of PWM rectifier

Sp	Sq	Selected vector
1	1	V0,7,Vk+2,Vk+3
1	0	Vk-1,Vk-2
0	1	Vk+1
0	0	Vk

Table II: Comparison of vectors in case of P and Q Increasing [1]

	$\|\Delta P\|$	$\|\Delta Q\|$
V0,7	Small to medium	small
Vk+2	Medium to small	big
Vk+3	big	medium

Table III: Comparison of vectors in case of P increasing and Q decreasing [1]

	$\|\Delta P\|$	$\|\Delta Q\|$
Vk-1	Big	small
Vk-2	Small	big

One special case of Table I. is selected to obtain active vector as shown in Table IV. Similar results can be obtained from the other vectors also. Table IV. is used to study the comparison of DPC models.

Table IV: Active vector selection for the improved DPC with duty cycle control

Sp	Sq	Selected vector
1	1	Vk+3
1	0	Vk-1,
0	1	Vk+1
0	0	Vk

Duty cycle is the ratio of the applied duration of the active vector to the whole period and for duty cycle =1 the improved DPC will act as STDPC . Since active power is depending on the fractional control of duty cycle 'd' it will try to improve steady performance of the rectifier .From equation (6) slopes of the active power for the active vector s1 and for null vector s2 can be obtained . A typical waveform employing active as well as null vector is as shown.

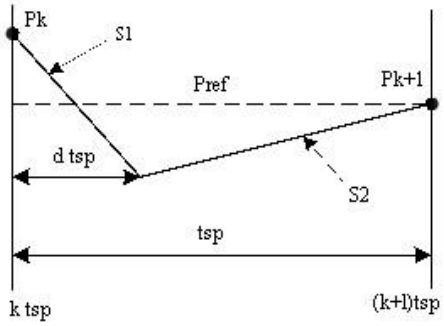


Fig.6 waveform of active power when both active and null vector is employed for one period [1]

Supposing that P reaches its reference value in deadbeat fashion, the equation for P can be:

$$p^{k+1} = p^k + s1.d.tsp + s2.(1-d).tsp \quad (13)$$

i.e.

$$p^{ref} = p^k + s1.d.tsp + s2.(1-d).tsp \quad (14)$$

from (13) & (14) the optimized duty cycle 'd' can be given as :

$$d = \frac{p^{ref} - p^k - s2.tsp}{(s1-s2)\,tsp} \quad (15)$$

The above equation for duty cycle requires accurate knowledge of slopes s1 and s2 of active powers. Unlike equation (6) where the power slopes were dependant on information of input inductance and resistance, this technique doesn't require them. Hence trying to maintain the system simplicity and robustness. By expanding equation (15) following equation can be obtained:

$$d = \frac{p^{ref} - p^k}{(s1-s2)tsp} + \frac{-s2.tsp}{(s1-s2)tsp} \quad (16)$$

Considering the denominator to be constant the parameter dependence is eliminated in first term, whereas second term is complex and parameter dependent term. Here the numerator s2 is active power slope caused by the null vector which has small but constant influence over the reactive power. Hence the first term can reflects the regulation of active power whereas the second reflects regulation of reactive power.

Thus the final expression for this algorithm can be given as:

$$d = \left| \frac{p^{ref} - p^k}{C_p} \right| + \left| \frac{Q^{ref} - Q^k}{C_q} \right| \quad (17)$$

Based on the variations in Cp and Cq the accuracy of the duty cycle 'd' influence partly the steady performance and dynamic response, but it would not cause much influence on the stability of system, because the mechanism of STDPC still works to ensure the system is stable. DPC has high performance control logic for PWM rectifier based on instantaneous power theory which was first proposed by Akaji in his paper.

Extensive simulations showed that to achieve good steady state and dynamic performance.

$$C_p = C_q = \frac{V_{dc}}{L} e^{peak} tsp \quad (18)$$

Where e^{peak} is the peak phase value of grid voltage.

IV. RESULTS OF SIMULATIONS

The simulation model is developed in MATLAB/Simulink environment to verify the effectiveness of the control method under steady state conditions. The waveforms obtained confirm the improvement in the DPC with minimum distortion and less %THD. The simulations are carried out for a sampling frequency of 20 KHz and 40 KHz the effect of variation in the result can be observed significantly.

The system parameters used for simulations are Line resistance R = 0.3 Ω, L = 10mH, Vdc = 300V, DC bus capacitor = 2350µ F, active power constant gain Cp =183.7 W, Reactive power constant gain Cq = 183.7 Var, fs = 50 Hz, tsp = 50µ sec.

Table V: % THD for different values of sampling frequency (Qref = 0, P ref = 900 W)

Configuration Sampling frequency	Duty cycle based DPC THD%
20KHz	5.27
40 KHz	8.46

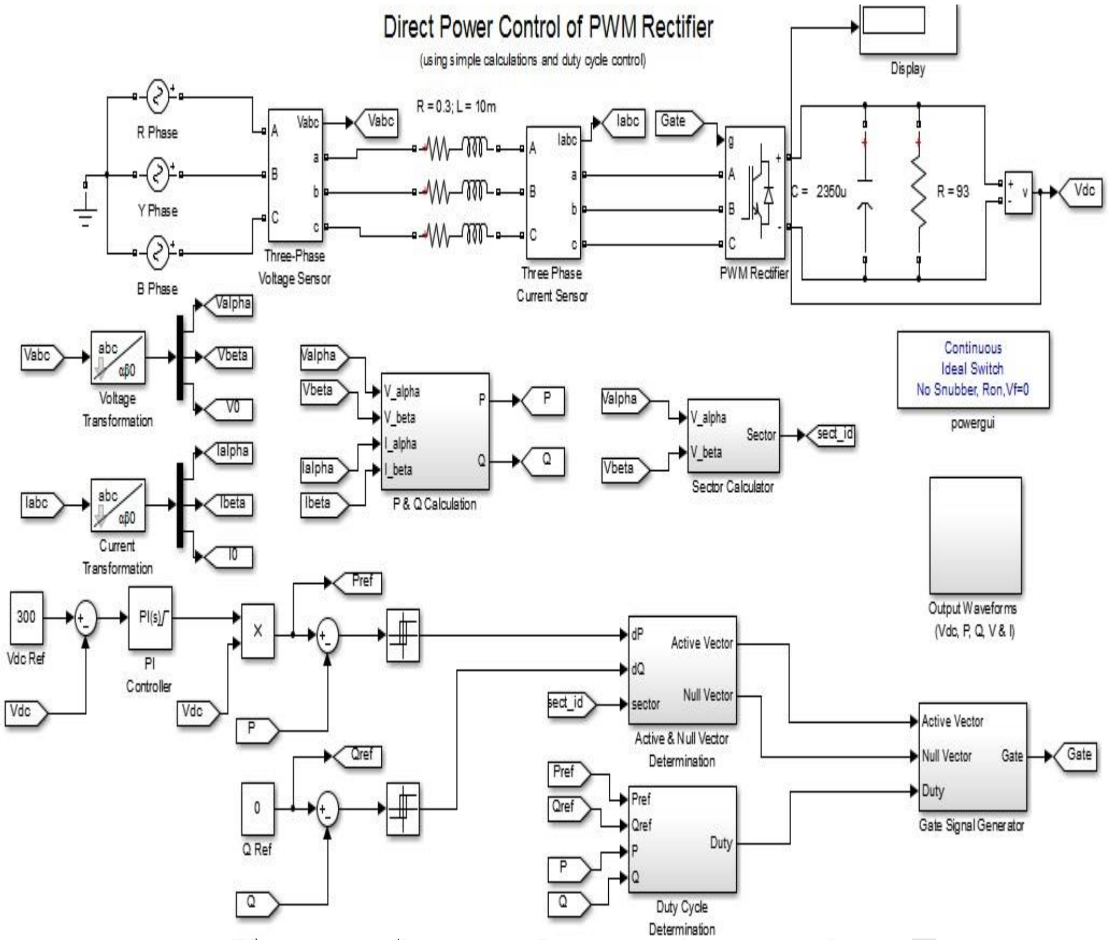
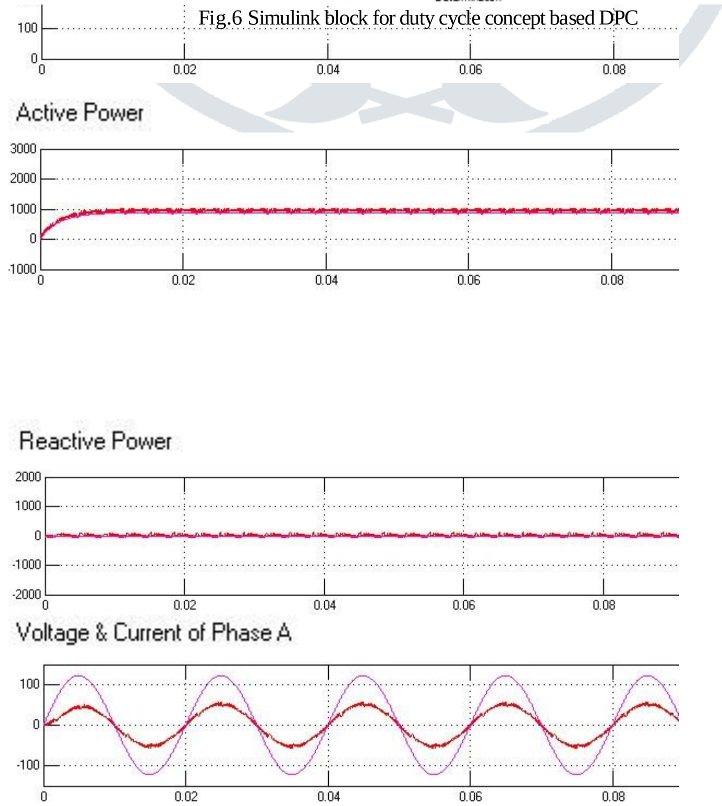


Fig.6 Simulink block for duty cycle concept based DPC



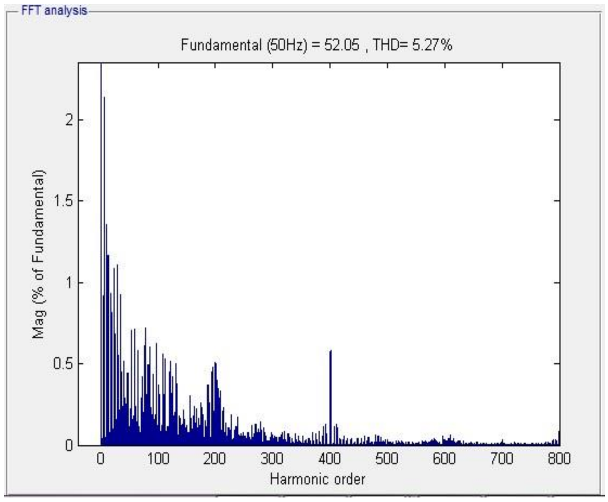


Fig 8 simulation of DPC with 20 Khz sampling frequency

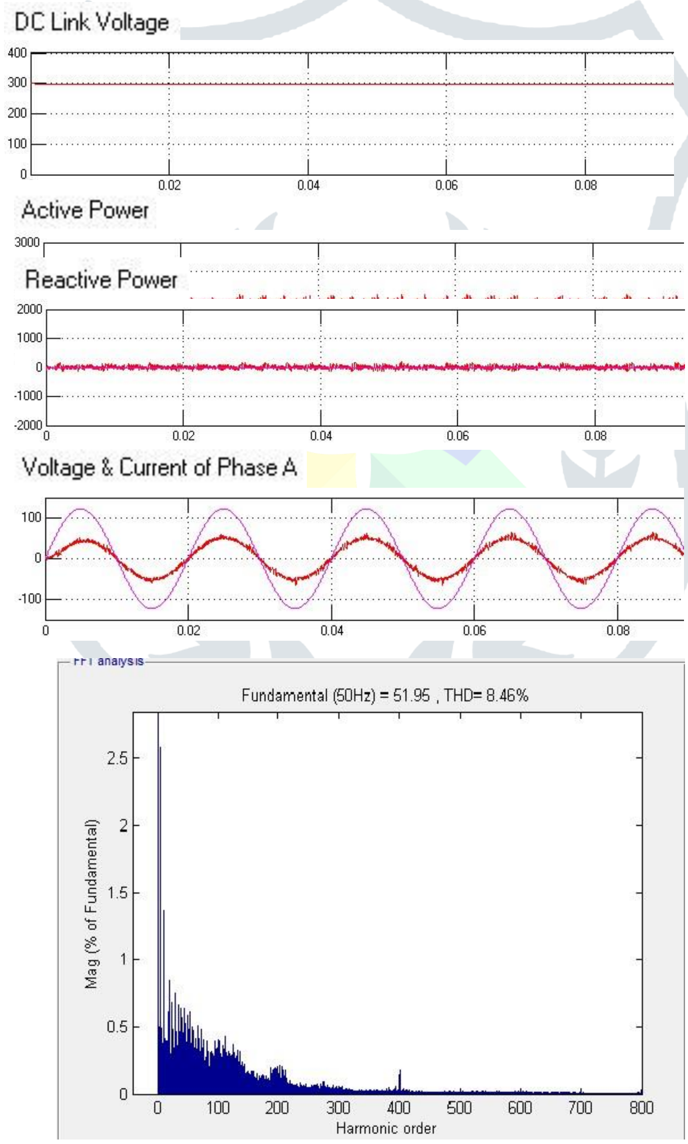


Fig 8 simulation of DPC with 40 Khz sampling frequency

V. CONCLUSION

A DPC with simple approach of with duty cycle control was simulated and studied for harmonic distortion, power factor, switching losses and sinusoidal input ripple. It is found that using Direct Power Control and its controlled algorithm the performance of the rectifier greatly improves due to less harmonic distortion, good power factor, less switching loss and sinusoidal input current waveform. The main advantage of using duty cycle in DPC is that the rectifier parameters are independent of the control and only a fraction of control period is used. Also the methodology used in DPC is of instantaneous active and reactive power theory which are regulated separately so the control does not require inner current loop as required for voltage oriented control thus giving high dynamic performance.

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REFERENCES

[1]. "Performance Improvement of Direct Power Control of PWM Rectifier With Simple Calculation," Yongchang Zhang, Member, IEEE, Zhengxi Li, Senior Member, IEEE, Yingchao Zhang, Wei Xie, Zhengguo Piao, and Changbin Hu, IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 28, NO. 7, JULY 2013

[2]. "Model Predictive Direct Power Control of a PWM Rectifier With Duty Cycle Optimization" Yongchang Zhang, Member, IEEE, Wei Xie, Zhengxi Li, Senior Member, IEEE, and Yingchao Zhang , IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 28, NO. 11, NOVEMBER 2013

[3]. " Predictive Direct Power Control of Three-Phase Pulsewidth Modulation (PWM) Rectifier Using Space-Vector Modulation (SVM)" Abdelouahab Bouafia, Jean-Paul Gaubert, Member, IEEE, and Fateh Krim, Senior Member, IEEE , IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 25, NO. 1, JANUARY 2010

[4] "DPC of a Three Phase Rectifier Based on Positive Sequence Detection" PanfiloR.MartinezRodriguez, *Member, IEEE*, Gerar doEscobar, *SeniorMember,IEEE*, AndresA.ValdezFernandez, *Member, IEEE*, MichaelHernandezGomez,andJoseM.Sosa,*Me mber,IEEE* I EEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS,VOL.61,NO.8,AUGUST 2014

[5]. "Optimum Space Vector Computation Technique for Direct Power Control" Jose A. Restrepo, Member, IEEE, Jose M. Aller, Julio C. Viola, Alexander Bueno, and Thomas G. Habetler, Fellow, IEEE IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 24, NO. 6, JUNE 2009

[6]. "Comparative study of SVPWM (space vector pulse width modulation) & SPWM (sinusoidal pulse width modulation) based three phase voltage source inverters for variable speed drive" ICSI CCST 2013 IOP Publishing IOP Conf. Waheed Ahmed1,2 and Syed M Usman Ali1 1 Department of Electronic Engineering, NED University of Engineering & Technology, University Road, Karachi -75270, Pakistan. Series: Materials Science and Engineering 51 (2013)

[7]. Simple Direct Power Control of Three-Phase PWM Rectifier Using Space-Vector Modulation (DPC-SVM) Mariusz Malinowski, Member, IEEE, Marek Jasinski, Student Member, IEEE, and Marian P. Kazmierkowski, Fellow, IEEE IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 51, NO. 2, APRIL 2004

[8]. Harmonic Mitigation Using 12-Pulse AC–DC Converter in Vector-Controlled Induction Motor Drives Bhim Singh, Senior Member, IEEE, G. Bhuvaneswari, Senior Member, IEEE, and Vipin Garg, Member, IEEE.