THD Reduction of A Current Source Rectifier-DC Motor Drive Using Single Tuned Filters

Omar Turath Tawfeeq

***Abstract*— A current source rectifier (CSR) is commonly used to supply a DC Motor with variable voltage for variable speed applications. A study of THD Reduction using single tuned filters employed to obtain the required low harmonic distortion and nearly unity power factor in A.C supply current over a wide range of operating shaft speed.**

The external performances of a three-phase CSR-fed separately excited DC motor drive such as power factor, harmonics factor, and efficiency using sinusoidal pulse width modulation (SPWM) control technique are obtained for different speeds and modulation indexes. Separately excited DC motors with armature voltage control provides constant torque operation.

The effectiveness of the proposed system (2.3-kW 13A DC motor drive) was verified through computer Matlab simulations.

Key-Words: Current source rectifier, DC Drive, THD Reduction, Single tuned filters, SPWM.

I. INTRODUCTION

In recent years, increasing emphasis on power quality has directed researchers towards proposing and developing inherently clean new power converter topologies. These converters operate at nearly unity power factor, inject very low harmonic content into the supply and work at relatively high converter efficiencies.

DC Drives of medium and large horsepower are fed from three-phase A.C supply system via three-phase controlled thyristor converters. The main disadvantages associated with such converters are poor supply power factor, especially at large phase angle delays, generation of considerable amounts of lower order harmonic currents in the AC supply line, and generation of ripple in the output current.

Buck type PWM current source rectifier (CSR) offers a good solution for direct conversion of AC to DC at high power densities to meet the strict power factor penalty limits imposed by electricity authorities, and input line current harmonic distortion limits dictated by various harmonic standards such as IEEE Std.519, IEC 555, etc [1,2]. A low-pass damped LC filter is connected to the input side of the CSR to filter out the switching frequency harmonic components in the line currents. Furthermore, it injects significant amounts of low-frequency Super harmonics such as fifth, seventh, and 11th current harmonic components into the supply. Since the variation in reactive power consumption is usually fast for some of the DC motor drives operating in iron and steel plants, this choice would make necessary the use of costly reactive power compensation and filtering solutions such as, active power filters or dynamic VAR generators designed in the form of passive shunt filters. However, the buck-type PWM rectifier chosen inherently operates at power factor nearly unity in a wide speed range, and does not produce any low-order harmonics such as the fifth, seventh, 11, and 13 times the supply frequency. Since the chosen modulation technique is the sinusoidal PWM this converter produces harmonics as the sidebands of the switching frequency and its multiples. With the present semiconductor technology, switching frequency is in the range of 10–20 kHz in the moderate power range up to 100 kW for hard switching. This makes necessary the use of a high frequency input filter which is smaller in size, has a fixed configuration, and hence is more reliable, and cheaper in comparison with that of a six-pulse line-commutated A.C–DC converter [1,3]. Filtering harmonics using passive filter is one of the earliest methods used to address harmonic mitigation issues. Passive filters have been used in power system to mitigate harmonic distortions primarily due to their low cost[4].

This paper deals with the design of single tuned filters used to reduce THD of input current for three phase buck type SPWM rectifier fed DC motor drive.

Also Operating characteristics of buck type SPWM rectifier in variable speed DC motor application are given in the paper using Matlab (Simulink).

Manuscript received November 2013.

Omar Turath Tawfeeq, Electrical Department, University of Mosul/ College of Engineering/ Ninenava-Iraq.

II. SYSTEM DESCRIPTION

The Figure 1. shows the circuit diagram of a three phase SPWM current source rectifier (CSR) fed DC-drive (single quadrant) with single tuned filters (STF) from three phase A.C source side using Matlab (Simulink) .

The PWM CSR rectifier consists of 6 IGBTs connected in series with 6 diodes full bridge with freewheeling diode resulting in unidirectional current flow. A shunt (STF) with small inductance (Lss) in series with supply connected to the input side of the rectifier to filter out the switching frequency harmonics components in the line currents.

In the load side (DC motor) the switching frequency harmonics are filtered out with a damped output filter (series inductance (Ld.c) with shunt capacitance(Cl)).

PWM techniques have been commonly used in voltage and current-source inverters (VSIs and CSIs, respectively) of variable-frequency A.C motor drives. The control of unity-PF buck-type rectifiers is also based on these techniques for low distortion in supply currents [3].

In this work, the well-known, sinusoidal PWM technique is chosen to construct the switching signals. SPWM technique is a very popular method of controlling the output voltage, (SPWM) has found a wide range of applications since the early development of PWM-VSI technology.

Although the control range of modulation index is relatively narrow. SPWM is a simple technique and has a good transient response [3,5].

In this method, a high-frequency triangle carrier wave (fc = 1050 Hz) is compared with a three-phase sinusoidal waveform, as shown in fig 2. The power devices in each phase are switched on at the intersection of sine and triangle waves. The amplitude of the output voltage are varied by varying The ratio of the amplitude of the sine waves to the amplitude of the carrier wave which is called the modulation index (M) and by phase angle (α) which is define as the phase shift between three phase A.C supply and three-phase sinusoidal waves intersection with triangle wave.

The harmonic components in a PWM wave are easily filtered because they are shifted to a higher-frequency region. It is desirable to have a high ratio of carrier frequency to fundamental frequency to reduce the harmonics of lower-frequency components [5].

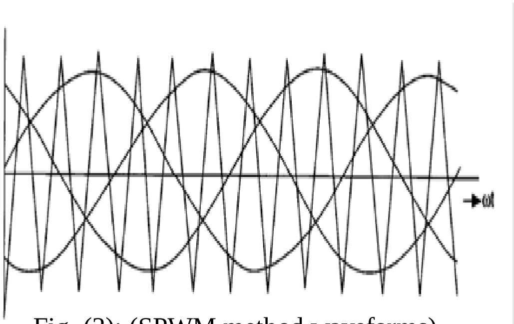


Fig. (2): (SPWM method waveforms)

Fig. (3): Single Tuned Filter

III. SINGLE TUNED FILTER

The most common type of shunt passive filters used in harmonic mitigation is the single tuned filter (STF) which is either a low pass or band pass filter. This type of filter is simple to design and the least expensive to implement .The configuration of a single tuned filter is depicted in Fig.3 [4]. Passive filter's general properties: They can be highly selective when losses are low, and the response is highly resonant. passive filters are simple, reliable, and cost-effective alternative but its performance is dependent of the load. Furthermore, power-factor correction becomes a very important issue for designing an electronic circuit involving a nonlinear load. Active and passive filters are used in this field [6].

The single-tuned filter [see Fig. 3] contains a capacitor in series with an inductor. The capacitor and inductor are sized such that the branch impedance is zero near a harmonic frequency, which bypasses that harmonic. The capacitor also provides reactive power compensation. A resistor can be used in order to adjust the tuning's sharpness and, as a consequence, the bandwidth. In this case, the quality factor is given by [7]

$$Q = \frac{\sqrt{L/C}}{R} \tag{1}$$

In an (STF) filter, the inductive and capacitive reactance at the tuned frequency should be equal [4].

$$Z = R + jw_n L + \frac{1}{jw_n c} = R \tag{2}$$

If X_o is the reactance of the capacitance or filter reactor at its tuned frequency

$$X_o = w_n L = \frac{1}{w_n C} = \sqrt{\frac{L}{C}} \tag{3}$$

IV. DESIGN OF SINGLE TUNED FILTER

For non-sinusoidal input voltage and current with nonlinear load the Apparent Power (S) can be calculate by using this equation [8,9,10].

$$S^2 = P^2 + Q^2 + D^2 \tag{4}$$

When P is real power, Q reactive power and D is distortion factor power. for filter design the non-active power G can be calculate as shown below

$$G^2 = \left(Q^2 + D^2\right) = S^2 - P^2 \tag{5}$$

$$G = \sqrt{S^2 - P^2}$$

the total value of filter capacitance required to compensate the non-active power can be calculated using equation below [8,11]

$$Ctotal = \frac{G}{\left(2\prod f * \left(V_{r.m.s}^2\right)\right)} \tag{6}$$

If the (STF) filters is use to eliminate multi harmonics components the value of capacitance (C) and inductance(L) of each filter branch can be calculate using this equation [8,11].

$$C_{branch} = \frac{C_{total}}{\text{Number of branch}} \tag{7}$$

$$\therefore L = \frac{1}{(2\pi f_n)^2 * C_{branch}} \tag{8}$$

Where

$$f_n = f\,(\text{Fundamental Frequency}) * n \tag{9}$$

When n harmonic order, and by using equation (1) above the value of resistance can be calculate

$$R = \frac{\sqrt{L/C}}{Q} \tag{10}$$

When

$50 < Q < 150$ [12].

V. SIMULATION RESULTS

The SPWM current source rectifier (CSR) based constant load torque DC motor drive system using (4STF) (show in fig.1) has been modeled in this research paper by using Matlab Simulink software, in order to control the DC motor speed by varying the DC output voltage applied to the motor, where this DC output voltage had been varied by varying the modulation index (M) and phase angle (α). The modeled system parameters values are shown in table 1.

Simulation results at M=0.9 and α=0 had shown non active power (G) was equal to 528VAR and that the dominantly effective harmonics are the (5^{th}, 7^{th}, 17^{th}, 19^{th}) harmonics in A.C supply.

To filter out these effective harmonics, four single tuned filters (STF) had been designed based on equations (7,8,10) mentioned above, where the values of the required capacitance, inductance and resistance had been calculated to composed this single tuned filters(STF). Table 2 shows the (STF) elements values required to filter out these four harmonics.

A.C current power factor and total harmonics distortion (THD) and the CSR system efficiency had been calculated based on Matlab-Simulink CSR model by using following well Known equations.

$$PF = \frac{1}{\sqrt{1+THD^2}} DF \qquad 11$$

$$THD = \sqrt{\left(\frac{I_s}{I_{s1}}\right)^2 - 1} \qquad 12$$

$$\eta = \frac{P_{out}}{P_{in}} \qquad 13$$

Where DF is Displacement factor, Is total input current, Is1 fundamental input current.

DC motor speed, voltage and current had also been calculated. Once by varying (M) while keeping (α) not change as shown in table 3 and then by keeping (M) not changed while varying (α) as shown in table 4.

Table 3 and 4 shows the THD reduction for input current at wide speed range and correction power factor at M=0.9 and α=0 when (STF) filters design at this values. it is to be noted that the leading power factor due to the dominant capacitive impact of the (STF) filters. As well as high efficiency of the (CSR).

Figure (4) shows the A.C. source voltage and current where current appears to be nearly sinusoidal due to the harmonics contents. Figure (5) shows the (STF) filters capacitance voltage and current. Figure (6) shows any IGBT power device voltage and current. Figure (7) shows the separately excited DC motor voltage, current and speed waveforms at M=0.9 and α=0 where the motor is constantly loaded (TL=17 N.m).

A. Figures and Tables

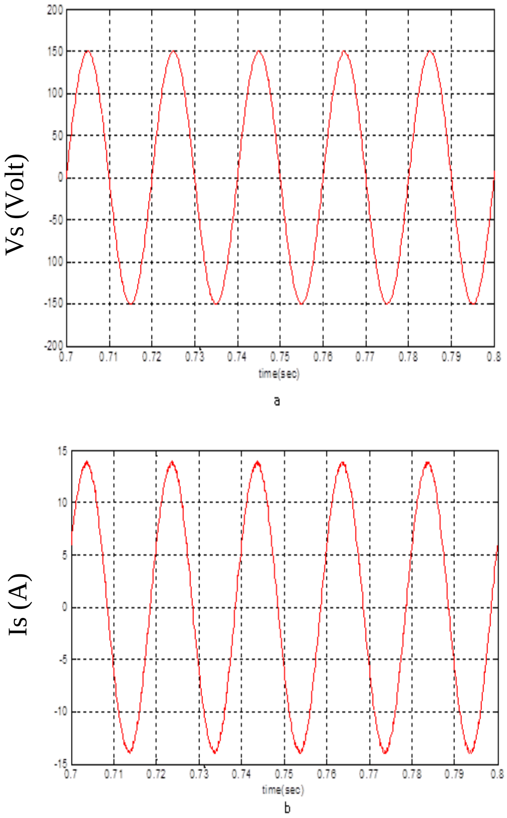


Fig (4): a) AC source input voltage
b) AC source input current

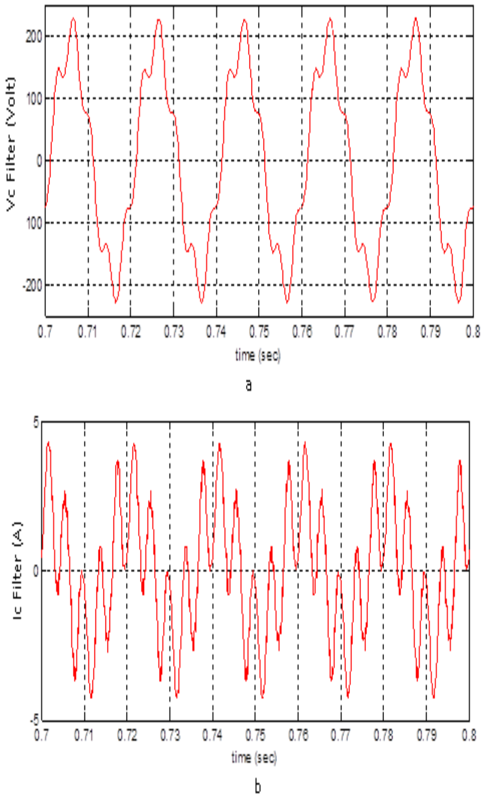


Fig (5): a- (STF) capacitance voltage
b- (STF) capacitance current

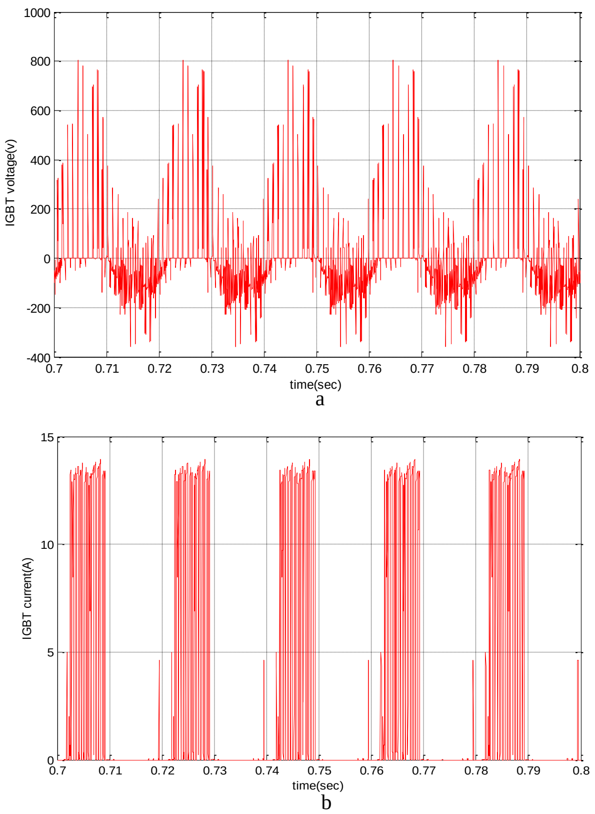


Fig (6): a- IGBT power device voltage
b- IGBT power device current

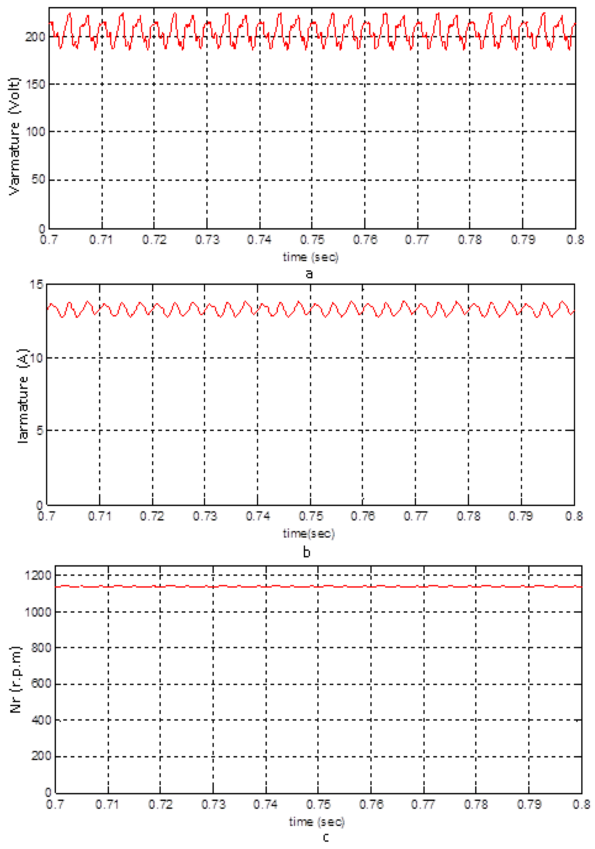


Fig. (7): a) Separately excited D.C motor voltage, b) Separately excited D.C motor current, c) Separately excited D.C motor speed

Table (1): System parameters

Input A.C supply per phase	
Maximum Input voltage (Vm)	150volt
Supply Frequency	50Hz
Supply resistance (Rs)	50mΩ
Supply inductance(Ls)	5mH
Series Supply inductance(Lss)	10mH
DC motor (Load side)	
Output power	2.3Kwatt
Rated speed	1250r.p.m
Armature resistance	2.2Ω
Armature inductance	17.5mH
Armature current	13A
Armature voltage	220volt
field resistance	246 Ω
field inductance	12H
field voltage	220volt
DC inductance (Ld.c)	50mH
Parallel capacitance (Cl)	10µF

Table (2): Four (STF) filters elements values

Harmonic order	C (µF)	L (mH)	R (Ω)
5^{th}	37	11	0.17
7^{th}	37	5.6	0.12
17^{th}	37	0.94	0.05
19^{th}	37	0.75	0.04

Table (3): External performances for CSR and D.C motor against M

M at α=0	THD %	PF	η%	N_r (r.p.m)	Varmature (Volt)	Iarmature (Amp)
0.95	2.6	0.92lead	94.8	1178	209.7	13.31
0.9	1.53	0.9lead	97	1143	204.1	13.26
0.7	2.3	0.8lead	99.8	837	156.4	12.82
0.5	2.15	0.64lead	89.3	567	114.5	12.5
0.3	3.95	0.4lead	85	229	61.3	12

Table (4): External performances for CSR and D.C motor against α

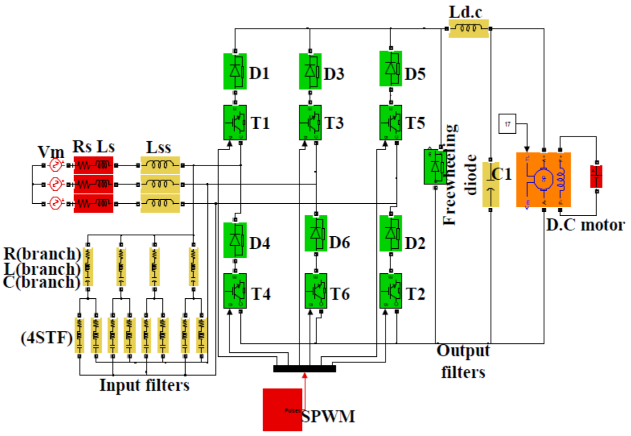
α at M=0.9	THD %	PF	η %	N_r (r.p.m)	Varmature (Volt)	Iarmature (Amp)
0	1.53	0.9lead	97	1143	204.1	13.26
30	1.79	0.8lead	96.5	1127	201.4	13.24
60	3.19	0.6lead	95.2	912	168.4	13.02
90	1.18	0.32lead	95.5	487	101.5	12.32
120	4.3	0.15lead	87.6	42	32.36	11.77

VI. CONCLUSION

In this study, SPWM current source rectifier (CSR) fed DC motor (1Q) with constant load torque using passive filter (four single tuned filters) in A.C supply side has been achieved by using Matlab Simulink. The external characteristics of a current source rectifier (CSR) such as (THD, PF, η) have been calculated, DC motor characteristics (armature voltage, current and shaft speed) had also been obtained by varying modulation index (M) and phase angle (α).

Furthermore voltages and currents waveforms for all system and motor speed waveform had also been taken at M=0.9 and α=0. In this paper Simulation results at M=0.9 and α=0 had shown that the dominantly effective harmonics are the (5^{th}, 7^{th}, 17^{th}, 19^{th}) harmonics in A.C supply to filter out these effective harmonics four single tuned filters (STF) had been designed, where the values of the required capacitance, inductance and resistance had been calculated to composed this single tuned filters (STF). and the quality factor (Q) has been chosen as 100.

The use of current source rectifier in combination with a simple and cheap input and output filter in DC motor applications introduces some opportunities such as lower input current harmonic, nearly unity power factor (leading) in limited range of varying modulation index (M) and phase angle (α).



REFERENCES

[1] H.F. Bilgin°+, K.N. Köse°, G. Zenginobuz°, M. Ermis°+, E. Nalçaci°+, I. Çadirci°+and H. Köse* , "A Unity Power Factor Buck Type PWM Rectifier for Medium/High Power DC Motor Drive Applications", °TÜBITAK-METU Information Technologies and Electronics Research Institute TR06531 Ankara-Turkey, (C) 2001 IEEE.

[2] SESHAGIRI R. DORADLA, C. NAGAMANI, AND SUBHANKAR SANYAL"A Sinusoidal Pulsewidth Modulated Three-Phase AC to DC Converter-Fed DC Motor Drive ", IEEE Transactions On Industry Applications, Vol. IA-21, No. 6, November/December 1985.

[3] Hazım Faruk Bilgin, K. Nadir Köse, Gürkan Zenginobuz, Muammer Ermis¸, Erbil Nalçacı, Is¸ık Çadırcı,, and Hasan Köse "A Unity-Power-Factor Buck-Type PWM Rectifier for Medium / High - Power DC Motor Drive Applications", IEEE Transactions On Industry Applications, Vol. 38, No. 5, September/October 2002

[4] Seema P. Diwan, Dr. H. P. Inamdar, and Dr. A. P. Vaidya" Simulation Studies of Shunt Passive Harmonic Filters: Six Pulse Rectifier Load . Power Factor Improvement and Harmonic Control", ACEEE Int. J. on Electrical and Power Engineering, Vol. 02, No. 01, Feb 2011.

[5] Rajashekara, K., Bhat, A.K.S., Bose, B.K. "Power Electronics" The Electrical Engineering Handbook Ed. Richard C. Dorf Boca Raton: CRC Press LLC, 2000.

[6] Ersoy Kelebekler, Ali Bekir Yildiz, "Analysis of Passive and Active Filters Using Modified Nodal Approach", Compatibility in Power Electronics, CPE '07, Gdansk, Issue Date: May 29-June 1 2007, IEEE.

[7] Alexandre B. Nassif, WilsunXu, and WalmirFreitas, "An Investigation on the Selection of Filter Topologies for Passive Filter Applications", IEEE Vol. 24, No. 3, July, 2009.

[8] Bashar Abbas Fadeel , "Analysis and Design of Passive Filter to Reduce Line Current Harmonics for Controlled Rectifiers", M. Sc. Thesis, University of Mosul, 2011. (in Arabic).

[9] W. SHEPHERD and P.ZAND, "Energy Flow And Power Factor In Nonsinusoidal Circuits", First published, Cambridge University Press, 1979.

[10] IEEE Standard 1459-2000, "IEEE Trial-Use Standard Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions", 2000, IEEE.

[11] Jos Arrillaga and Neville R. Watson, "Power System Harmonics", second Edition, John Wiley & Sons, Ltd, England, 2003.

[12] Muhammad H. Rashid, "Power Electronics: Circuits, Devices and Applications", Third Edition, Pearson Prentice Hall, U.S.A, 2004.

Omar Turath Tawfeeq. B.Sc in Electrical Engineering / Power and Machines from University of Mosul in 2003with grade Good and The rank is First. MSc in Electrical Engineering / Power and Machines from Electrical Eng. Dept. / College of Engineering / University of Mosul in 2006 with grade V. Good. Member, Iraqi Engineering Society. Currently he is assist lecturer at the Department Electrical Engineering, University of Mosul since 2006.