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Single Tuned Passive Harmonics Filters Design For A Buck Type Rectifier D.C Motor Drive Using Fuzzy Controller

Omar Turath Tawfeeq

***Abstract*— nowadays, passive harmonic filters are the preferred mitigation scheme for harmonics in power systems. which are installed according to system topology and to the engineer's judgment .This paper presents a study and design of a single tuned passive harmonics filters to minimize harmonic distortion caused by a harmonic source such as D.C drive. The non linear load considered in this paper is three phase Buck type rectifier fed D.C Motor drive (variable torque) with speed control of a separately excited D.C motor using fuzzy model reference speed controller. The system has been implemented using Matlab/Simulink software. The simulation results show that presenting controller give good performance in variable load disturbance.**

***Index Terms*—passive harmonic filters, buck rectifier, D.C drive, fuzzy speed controller.**

I. INTRODUCTION

The speed of D.C motors can be adjusted within wide boundaries so that this provides easy controllability and high performance. D.C motors used in many applications such as steel rolling mills, electric trains, electric vehicles, electric cranes and robotic manipulators require speed controllers. The most flexible control is obtained by means of separately excited D.C Motor in which the armature and field circuits are provided with separate sources. For the armature source a controlled rectifier or chopper is required. Armature voltage control method is used to vary the speed up to the rated speed and the motor operates in the constant torque region [1]. In recent decades, with the development of modern science and technology, the power electronic technology was widely used in power system. The traditional diode rectifier and the use of nonlinear loads can increase the total harmonic distortion of the input current, and highly pollute the power supply system's [2]. Nowadays, passive harmonic filters are the preferred mitigation scheme for harmonics in power systems. Several types of harmonic filters are available, which are installed according to system topology and to the engineer's judgment [3]. Buck-type PWM rectifier offers a good solution for direct conversion of A.C to D.C at high power densities to meet the strict PF 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.[4]. This paper deals with the analysis and design of single tuned passive harmonic filters used to reduce total harmonics distortion (THD) of input A.C current for three phase sinusoidal pulse width modulation (SPWM) buck rectifier fed D.C motor drive (variable torque) with fuzzy speed controller. Also Operating characteristics of buck rectifier in variable load D.C motor application are given in this paper using Matlab (Simulink). Figure (1) shows the system block diagram.

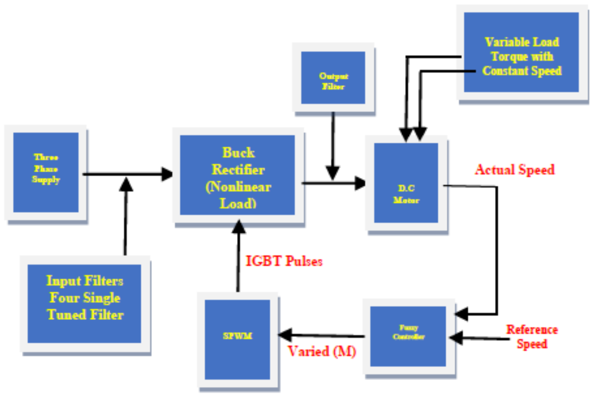

Fig (1): D.C Motor Drive System Block Diagram

II. SYSTEM DESCRIPTION

The Figure 2. Shows the circuit diagram of a three-phase SPWM buck rectifier fed D.C-motor drive (single quadrant) with fuzzy speed controller and four single tuned filters (4STF) from three phase A.C source side using Matlab (Simulink).

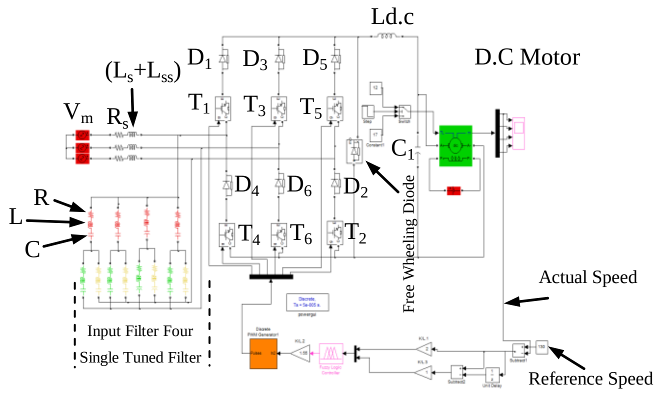

Fig (2): Circuit diagram of a three-phase buck rectifier fed D.C-motor drive with fuzzy speed controller using Matlab (Simulink)

A. Three Phase Buck Rectifier

The buck rectifier consists of 6 IGBTs connected in series with 6 diodes full bridge with freewheeling diode resulting in unidirectional current flow. A shunt (4STF) 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 (D.C motor separately exited), the switching frequency harmonics are filtered out with a damped output filter (series inductance (Ld.c) with shunt capacitance (Cl)). Table (1) shows the parameters of input A.C source with filters and D.C motor parameters with output filters.

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

A. Sinusoidal Pulse Width Modulation (SPWM)

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 [4]. 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 [4, 5]. In this method, a high-frequency triangle carrier wave (fc = 1050 Hz) is compared with a three-phase sinusoidal waveform, as shown in figure 3. 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].

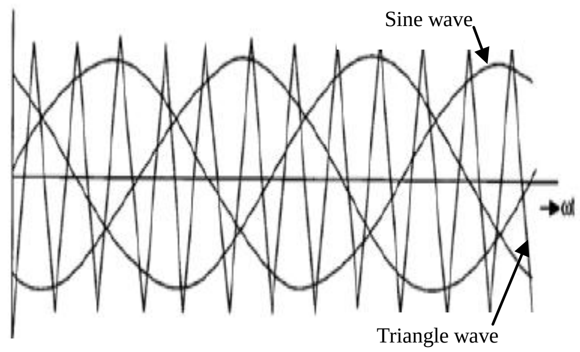

Fig (3): SPWM technique waveforms

B. Fuzzy Logic Controller Design

First, Why Should We Use Fuzzy Controllers? Fuzzy logic controller is very robust, can be easily modified, can use multiple inputs and outputs sources, much simpler than its predecessors (linear algebraic equations), very quick and cheaper to implement [6, 7]. Fuzzy logic controller has been designed for writing its inputs as : The error e(t) and the error change Δe(t) of the output voltage .The linguistic variables are defined as (N, NS, Z, PS, P)where N means negative, NS negative small, Z zero, PS positive small, P positive. Triangular member ship functions of the fuzzy logic controller are considered. The fuzzy rules are summarized in table (2). The surgeno type of fuzzy inference engine is considered [8]. The error range are taken between (-100 and 100) as shown in Figure (4), and range of error change are taken between (-50 and 50) as shown in Figure (5). The fuzzy logic controller gains are computed using trial and error method to improve the system performance [8]. The Fuzzy Logic Controller gains when reference speed equal to 130 Rad /sec are G0=20.5, G1=1.1, H=1.55 at load torque change from 12-17N.m and from 12-10 N.m.

Table (2): Fuzzy logic controller rules base

e/Δe	N	NS	Z	PS	P
NB	N	N	N	NS	Z
NS	N	N	NS	Z	PS
ZE	N	NS	Z	PS	P
PS	NS	Z	PS	P	P
PB	Z	PS	P	P	P

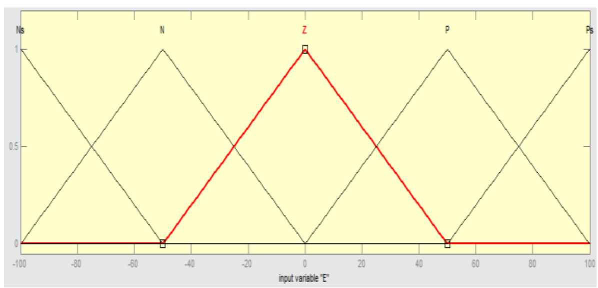

Fig (4): Error member ship function

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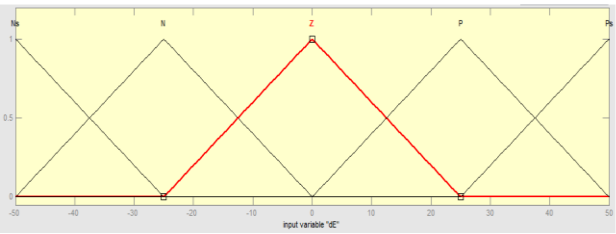

Fig (5): Change in error member ship function

C. 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 Figure (6) [9]. 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 [10]. The single-tuned filter [see Figure 6] 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 [11].

$$Q=\frac{\sqrt{L/C}}{R} \qquad \dots (1)$$

In an (STF) filter, the inductive and capacitive reactance at the tuned frequency should be equal [9].

$$Z=R+jw_nL+\frac{1}{jw_nc}=R \qquad \dots (2)$$

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

$$X_o=w_nL=\frac{1}{w_nC}=\sqrt{\frac{L}{C}} \qquad \dots (3)$$

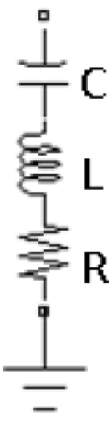

Fig (6): Single tuned filter

III. 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 [12, 13, and 14].

$$S^2=P^2+Q^2+D^2 \qquad \dots (4)$$

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.

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

The total value of filter capacitance required to compensate the non-active power can be calculated using equation below [12, 15].

$$C_{total}=\frac{G}{\left(2\pi f\times\left(V_{r.m.s}^2\right)\right)} \qquad \dots (6)$$

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 [12, 15].

$$C_{branch}=\frac{C_{total}}{\text{Number of branch}} \qquad \dots (7)$$

$$\therefore L=\frac{1}{\left(2\pi f_n\right)^2\times C_{branch}} \qquad \dots (8)$$

Where

$$f_n=f\,(\text{Fundamental Frequency})\times n \qquad \dots (9)$$

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

$$R=\frac{\sqrt{L/C}}{Q} \qquad \dots (10)$$

When
$50 < Q < 150$ [16].

IV. SIMULATION RESULTS

The SPWM current source rectifier (CSR) based variable load torque D.C motor drive system using (4STF) using fuzzy speed controller (show in figure.2) has been modeled in this research paper by Matlab Simulink software, in order to control the D.C motor speed when load torque is changes the output D.C voltage applied to the motor had been varied by varying the modulation index (M) keeping (α = 20°) not changed using fuzzy controller. 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 528 VAR and that the dominantly effective harmonics are the (5th, 7th, 17th, 19th) harmonics in A.C supply. To filter out these effective harmonics, four single tuned filters (4STF) 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

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composed this single tuned filters (STF). Table 3 shows the (STF) elements values required to filter out these four harmonics.

Table 3: Four (STF) filters elements values

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

A.C current power factor (PF) and total harmonics distortion (THD) and the current source rectifier system efficiency had been calculated based on Matlab-Simulink as well as the settling time (tss), state steady error (ess) and over shoot(O.V.SH) when the load torque changes (from TL = 10 N.m to TL=17 N.m) increases or decreases. Table (4) Shown the results of comparison between open loop and close loop with fuzzy speed controller when reference speed (W = 130 Rad/sec).

Table (4): The results of comparison between open loop and Close loop system using fuzzy speed controller

	THD %	ess% before TL changed	ess% after TL changed	Efficiency %	Power Factor	O.V. SH %	tss
Open loop at TL=12-10 N.m	3.092	5	2.4	92	0.695	0	1.85
Close loop at TL=12-10 N.m	1.91	0.1	0.08	97	0.74	1.6	1.7
Open loop at TL=12-17 N.m	2.78	5	7.9	91	0.89	0	1.85
Close loop at TL=12-17 N.m	2.7	0.1	0.2	96.8	0.91	1.6	1.7

From the table above, it is show that the performance of the system for the settling time, state steady error, power factor (leading) and efficiency are improved. The THD kept low in open and close loop system. Figure (7) shows the Output open loop speed response with variable load torque (TL= 12- 17N.m) and (TL= 12- 10N.m). Figure (8) shows the Output closed loop speed response with variable load torque (TL= 12- 17N.m) and (TL= 12- 10N.m) using fuzzy speed controller to keep speed constant at reference value (W=130 rad/sec). Figure (9) shows the Output open loop torque response with variable load torque (TL= 12-17 and 12-10 N.m) and Figure (10) shows the Output closed loop torque response with variable load torque (TL= 12-17 and 12-10 N.m). Figure (11) gives Input voltage and current open loop and closed loop responses with variable load torque (TL= 12-10 N.m). Figure (12) gives Input voltage and current open loop and closed loop responses with variable load torque (TL= 12-17 N.m).

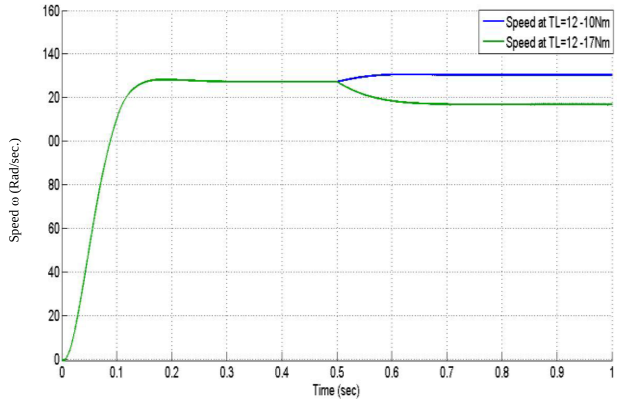

Fig (7): Output open loop speed response with variable load torque

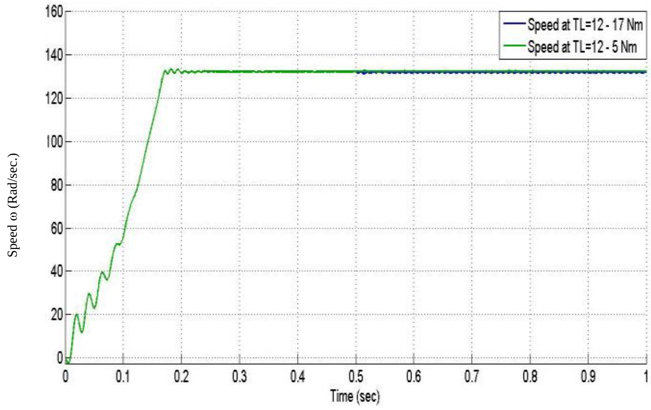

Fig (8): Output close loop speed response with variable load torque (TL= 12- 17 and 12-10 N.m)

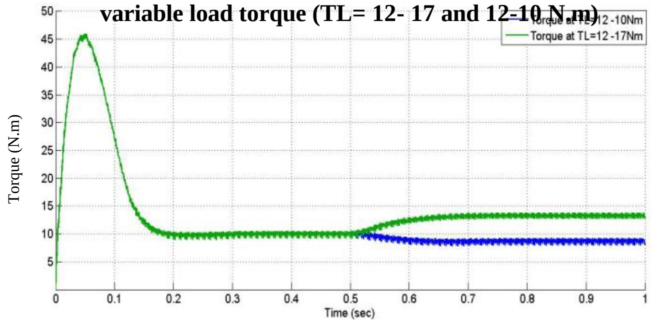

Fig (9): Output open loop torque response with variable load torque (TL= 12- 17 and 12-10 N.m)

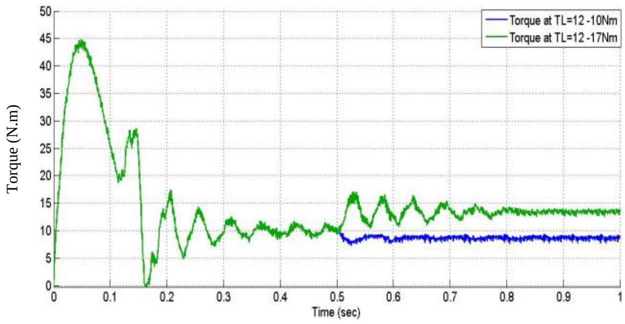

Fig (10): Output close loop torque response with variable load torque (TL= 12- 17 and 12-10 N.m)

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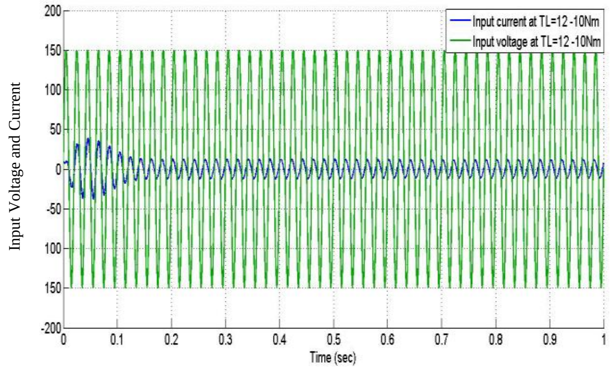
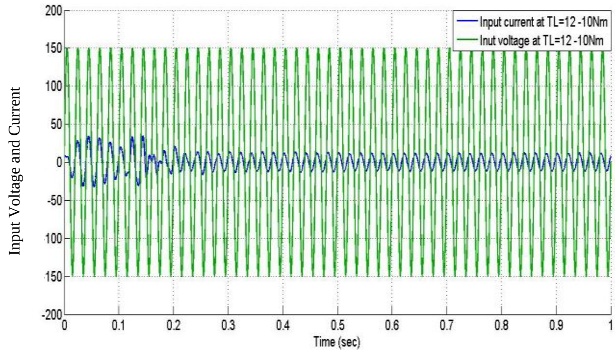
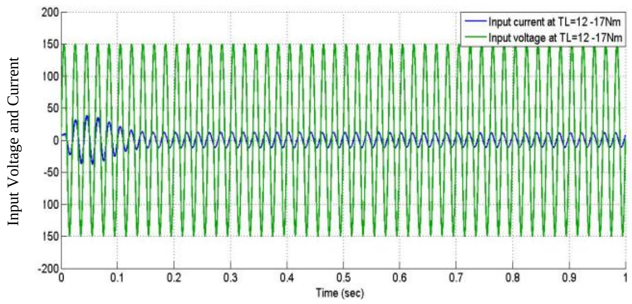


(a)



(b)

Fig (11):
a) Input voltage and current open response with variable load torque (TL= 12-10 N.m).
b) Input voltage and current closed loop response with variable load torque (TL= 12-10 N.m).



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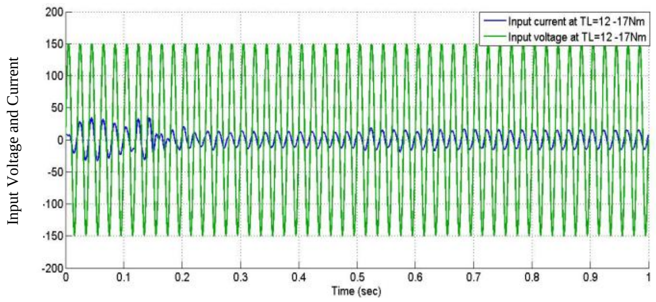

(b)

Fig (12):
a) Input voltage and current open response with variable load torque (TL= 12-17 N.m).
b) Input voltage and current closed loop response

V. CONCLUSION

In this study, SPWM buck rectifier fed D.C motor with variable load torque using passive filter (four single tuned filters) in A.C supply side with fuzzy speed controller has been achieved by using Matlab Simulink. This paper has presented a harmonic mitigation study in the D.C motor system. An investigation has been carried out to examine the effectiveness using the single tuned filters in eliminating harmonics. Simulation results in open loop system at M=0.9 and α=0° had shown non-active power (G) was equal to (528VAR) when the motor load torque at full load (TL=12N.m) and that the dominantly effective harmonics are the (5th, 7th, 17th, 19th) harmonics in A.C supply. To filter out these effective harmonics, four single tuned filters had been designed to filter out all harmonics. in order to control the D.C motor speed when the load torque changes (from TL=10 N.m to TL=17 N.m) increases or decreases about (1.6) from the rated value D.C output voltage had been varied by varying the modulation index (M) using fuzzy speed controller and kept phase angle constant at (α=20°). The performance of the system for the settling time, state steady error, over shoot, THD, power factor (leading) and efficiency are improved using fuzzy speed controller. The fuzzy logic controller gains are computed using trial and error method to improve the system performance.

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