Power quality improvement of sugar factories DC motor drive using hybrid filter

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Abstract

Power quality management is the main problem facing industry today. This problem is mainly due to the generation of electric network harmonics. The growing use of variable speed drives produces a large amount of harmonics in distribution systems because of the non-sinusoidal currents consumed by these drives. It is well known that for better quality of power, the voltage and current waveforms should be sinusoidal. But in actual practice it is somewhat distorted and this phenomenon is called "Harmonic Distortion". Voltage harmonics are generally present in the utility power supply network. Even though electronic and non-linear devices are flexible, economical and energy efficient, they may degrade power quality by creating harmonic currents consuming excessive reactive power. Harmonic can be reduced using filters. Two types of filters have been utilized for harmonic distortions suppression namely passive and active filters. The present paper provides a method for designing a new hybrid (passive and active) power filters to reduce harmonic distortion and hence improve the power factor, reduce the cost and overcome all above problems. The simulation results certificate that the present hybrid filter (HAPF) causes perfect harmonics and reactive power compensation characteristics. In this case the total harmonic distortion (THD) meet standard values according to the IEEE 519/1992. The practical results of the studied dc motor drive system have been validated and compared with computer simulation MATLAB model results. The simulation results of this non- linear studied system have been carried out with MATLAB Program 2010.

Keywords: ***Harmonic suppression; Hybrid Filter; MATLAB 7; Power Quality; Shunt Active Power Filter; Total Harmonic Distortion***

Introduction

Harmonic distortion is not a new phenomenon on power systems. Harmonic distortion was very small in the past when the designs of power systems were very simple and conservative [1,2]. But, nowadays the electronic equipments, used in commercial, industrial and residential installations became more powerful and versatile. As a result harmonic distortion has increased as well and power quality problems resulting from harmonics have been getting more and more attention by researchers [2]. Electronic power converter loads such as adjustable speed drives, electronic power supplies, dc motor drives, battery chargers, electronic ballasts and many other rectifier and inverter are the most important class of non linear loads producing high harmonic currents [3]. In four wire systems, harmonic current with frequency multiple by three will be added up in the neutral conductor, so that the current through this neutral reaches high values [4]. The three types of methods to mitigate harmonic are presented in this paper are namely the passive filter and the active power filter and the hybrid filter.

2- Harmonic Filtering Technique

There are many harmonic filters such as passive and active filters. Their essential difference, as illustrated later, stands on whether they provide a (passive) filtering action within a selected bandwidth or as a result of a real-time (active) monitoring process that leads to the injection of real-time canceling harmonic currents [5].

One of the most common methods for control of harmonic distortion in industry is the use of passive filtering techniques that make use of single-tuned or band-pass filters.

Some of passive filters are illustrated in Fig. (1).The following can be found under this category:

- **a)** Single-tuned filters.
- **b)** 1st order damped filter.
- **c)** 2nd order damped filter.
- **d)** C-Type filter.

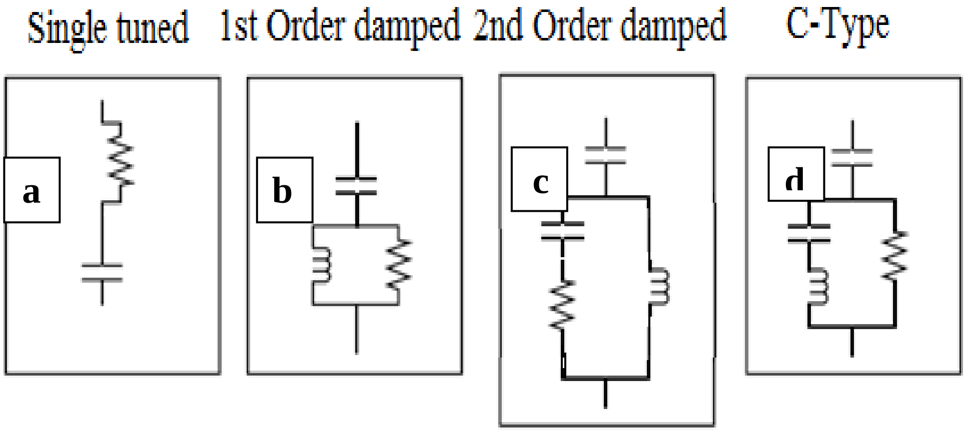

Fig. (1): Electric diagrams of passive filters.

3- Active Filters

The more sophisticated active filtering concepts operate in a wide frequency.

Range by adjusting their operation to the resultant harmonic spectrum. In this way, they are designed to inject harmonic currents to counter balance existing harmonic components as they show up in the distribution system. Active filters comprise series and parallel configurations.

3.1- Active Power Filters Configurations:

Parallel active filters have been recognized as a valid solution to current harmonic suppression and to reactive power compensation of non-linear loads. Series active harmonic filters are another type of filters used for voltage harmonic suppression. Hybrid active filter consisting of series harmonic filter and shunt passive LC filters is a third active filter type. A combination of shunt and series active filters is called "universal active harmonic filter". The selection of the active harmonic filter type depends on the source of harmonic problem [6].

3.2- Shunt Active Power Filter:

The more usual APF configuration is the shunt or parallel connection. Figure (2) shows the basic scheme of the connection, where an IGBT switching device represents the APF power block. The loads with current harmonics can be compensated by this APF configuration. A typical example of a current-source load is a rectifier with an inductive branch in dc side.

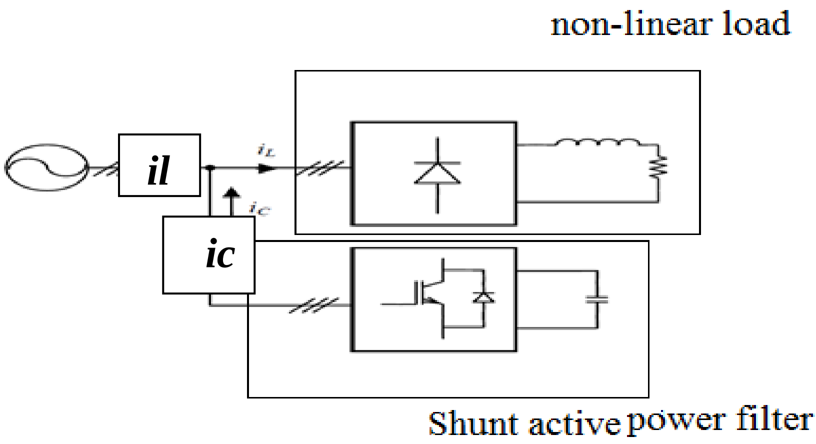

Fig. (2): Shunt active power filter scheme.

Figure (3) shows the basic performance of a shunt APF. The general aim is that the shunt APF will inject into the system a compensation current, i_C, to cancel the harmonic component of the load current, i_L. The source current i_S becomes sinusoidal after the compensation.

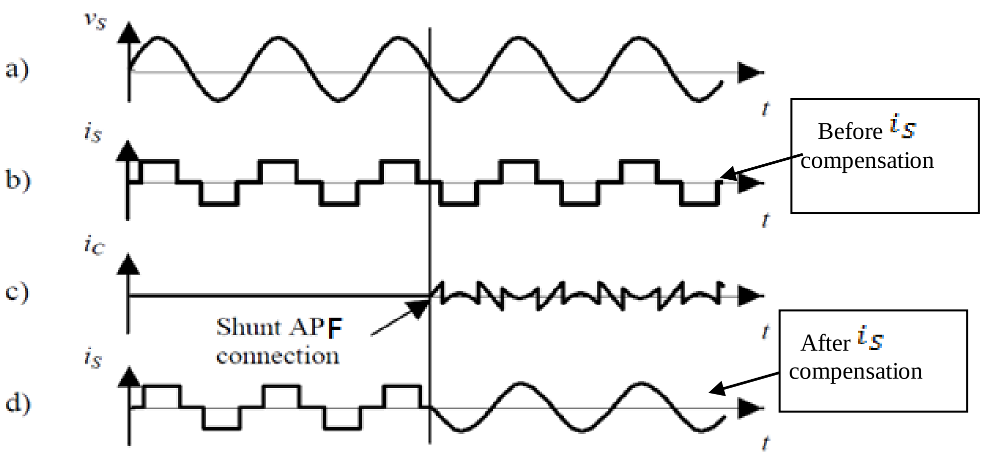

Fig. (3): Performance scheme of shunt APF.

The current waveform of a nonlinear load, consisting of three-phase diode rectifier with a highly inductive DC, is shown in Figure (3b). By connecting a shunt APF a compensation current is injected as shown in Figure

(3c), Figure (3d) shows the source current of the system after compensation. Before the compensation the source current have the shape of the load current, and after connecting the filter it becomes sinusoidal. In this example, the source voltage is sinusoidal, Figure (3a).

3.3- Hybrid Filters

Hybrid filters are a combination of passive and active filtering scheme. The next figures show some hybrid passive and active filters. The basic aim of these combinations is to reduce the cost of the static compensation. The passive filters are used to cancel the most relevant harmonics of the load, and the active filter is dedicated to improving the performance of passive filters or to cancel other harmonics components. As result, the power of the active filter is reduced, and the passive filter problems (resonances with the source impedance) are mitigated. In summary, the total cost decreases without reduction of the efficiency. Figure (6), Figure (7) and Figure (8) show the more usual hybrid topologies.

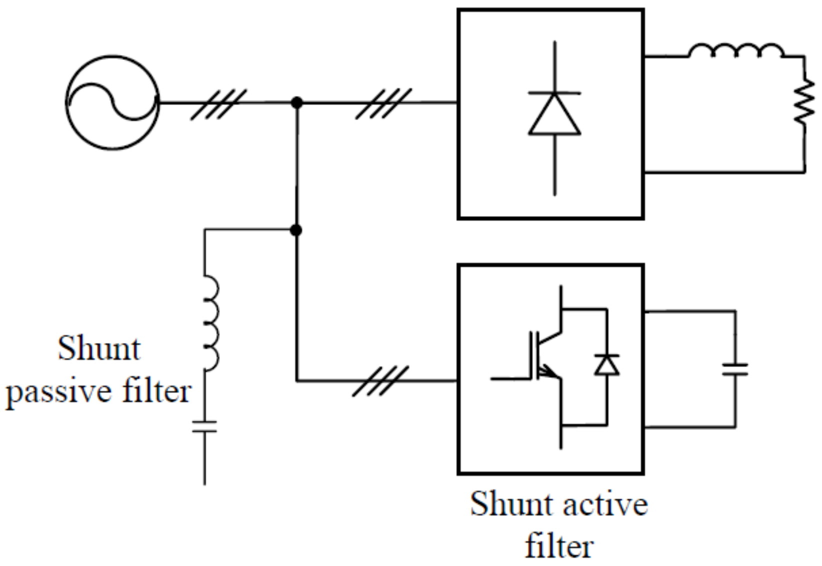

Fig. (6): Hybrid filter with a shunt passive filter and a shunt active filter.

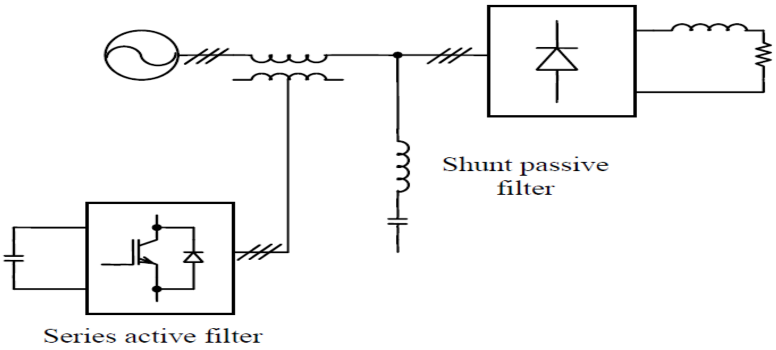

Fig. (7): Hybrid filter with a shunt passive filter and a series active filter.

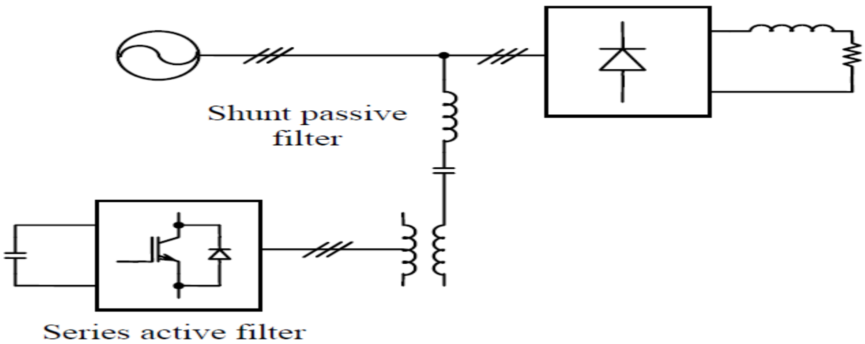

Fig. (8): A shunt passive filter and an active filter in series with it.

The passive filter is designed with some LC branches resonant to some harmonics or adjusted as high-pass filter.

1.4.Description of DC Motor Drive (DCM) case study

Fig. (1.9) illustrates the basic circuit description of the studied DCM , DC DRIVE consists of The DC motor, the three-phase full converter, The parameters values of the studied case are listed in the Table (1) below.

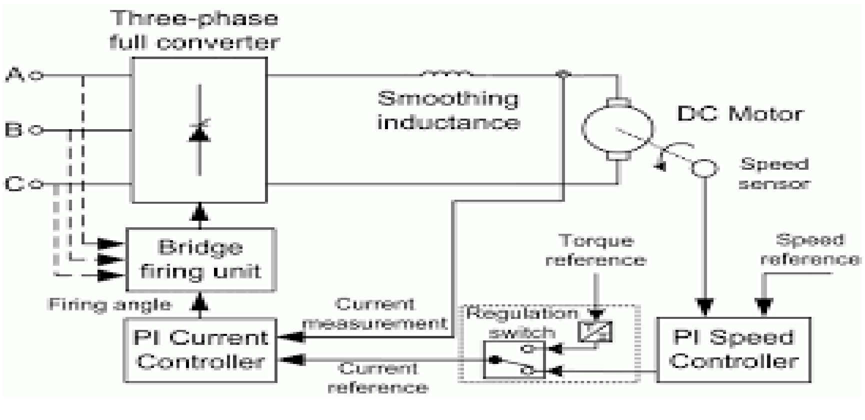

Fig. (9): Basic circuits configuration of the studied DCM

The machine is separately excited with a constant DC field voltage source. There is thus no field voltage control. By default, the field current is set to its steady-state value when a simulation is started.

The armature voltage is provided by a three-phase rectifier controlled by two PI controllers. Armature current oscillations are reduced by a smoothing inductance connected in series with the armature circuit.

Table (1.1) : the values of DC MOTOR DRIVE system parameters

Parameter	The value
DC Motor Parameter	200 HP, separate excitation
Rated {voltage, current, speed}	440Vdc.340 Adc. 1100 rpm
Excitation (voltage, current)	310Vdc.1Adc
Armature resistance &inductance, Ra, La	0.076Ω,0.00157 H
Field resistance &inductance. Rf,Lf	310Ω.232.5 H
Field armature mutual inductance	3.32 H
DCM drive power electronics	Thyristor controlled rectifier
Snubber resistance& capacitance Rs,Cs	3KΩ,35μF
Forward voltageVf&Ron	1.3V,1mΩ
Smoothing inductance	50mH
Input filter	
Inductance	0.049μH
Three phase supply voltage	
{voltage. frequency}	(400V .50 HZ)
Source resistance &inductance	0.005 Ω,0.00005H

4.1 - Practical Measurements and Results

The following represent some sample results to compare between practical and simulink results .This work was executed in edfuo sugar factory Harmonic analyzer – circuit AFI-M has been used. Total harmonic distortion THD for current wave has been found to be much higher than that for voltage, THD for different load time for the centrifugal sugar machine as shown in table (1.2a) ,table(1.2b)and table(1.2c) TIME (1).(2),(3) represent the different time loads for the machine.

Table (1.2a) practical Magnitude of harmonic order and THDi%., TIME(1)

H	Magnitude	H	Magnitude	
5	23.89%	21	0.58%	
7	3.17%	23	4.60%	THD(i)
11	1.98%	25	2.44%	24.6%
13	1.14%	31	1.91%	
17	3.54%			

Table (1.2b) practical Magnitude of harmonic order and THDi%. TIME(2)

H	Magnitude	H	Magnitude	
5	30.20%	21	0.76%	THD(i)
7	4.51%	23	4.46%	31.9%
11	9.31%	25	2.73%	
13	2.67%	31	2.47%	
17	5.76%			

Table (1.2c) practical Magnitude of harmonic order and THDi%.TIME(3)

H	Magnitude	H	Magnitude	
5	24.01%	21	0.69%	
7	5.11%	23	5.12%	
11	9.59%	25	3.03%	THD(i)
13	2.82%	31	2.96%	28%
15	0.50%			
17	7.24%			

Due to the power electronics circuitry of DCM drive, the input supply current to the drive contains various harmonics components.

The above results show low power factor around 0.3. The presence of 5th, 7th .11th and 13th harmonic currents and the %THD of input currents exceeds the standard values (5% according IEEE-519/1992).

4.2-DCM System Simulation Model without any types of filters

As shown in Fig (10) the DCM (study case) is considered as the source of current harmonic. To ensure the validity of the proposed system, comparison between the practical measurement results from power quality analyzer in Tables (1a,1b,1c) and simulation results from Mat lab Simulink Model in Fig. (11). It is noted that: the THD for the source current is approximately identical.

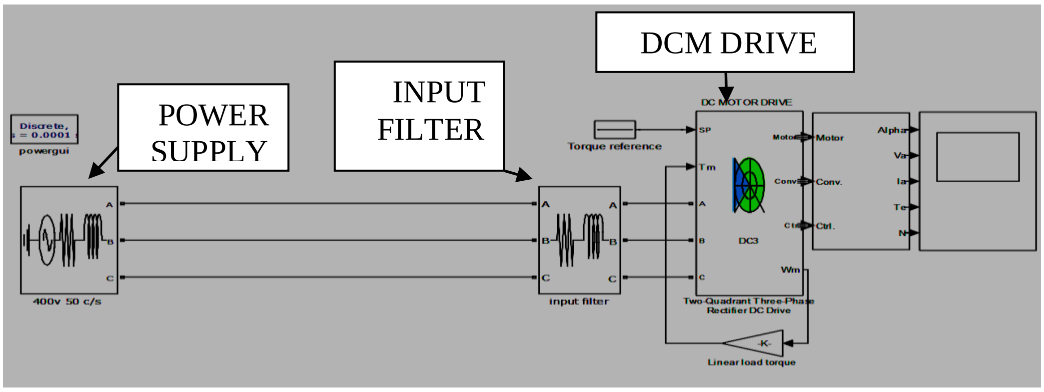

Fig. (10) : DCM drive system model without Filter

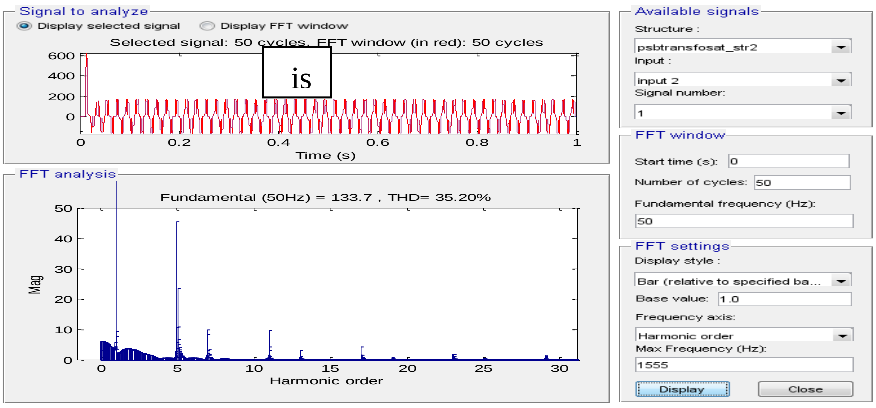

Fig. (11):the current waveform and Fast Fourier Transform (FFT) analysis

4.3-DC Drive Simulation Model With Shunt Passive Filter

At lower harmonic frequencies the most of the wave form have large percentage of harmonic distortion as compared to the high harmonic frequencies .for that reason single tuned filter STFs are designed to suppress these lower harmonic frequencies [7].

For suppressing the harmonics of six pulse AC to D C converter (dc drive model) four STFs are used for the 5th, 7th , 11th , and 13th harmonics and one second order damped filter tuned to hn>17 is used for eliminating the high order frequencies. Fig (12) show topology of the DC Drive with the proposed shunt passive power filter (PPF).

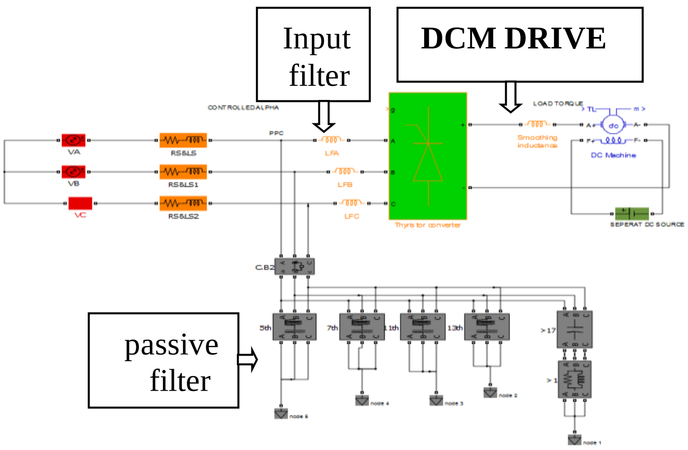

Fig. (12): The DC Drive with (PPF) Topology

5- Single Tuned Filter (STF) Design

The most commonly used PPF is the Single Tuned Filter (STF). This series RLC STF is simple, most common and inexpensive type as compared with other means for mitigation the harmonic problems [8][9]. This filter is connected in shunt with the main distribution system (at PCC) and is tuned to present low impedance to a particular harmonic frequency. Therefore, harmonic currents are diverted from the least impedance path through the PPF. For designing the STF, it is essential to select the appropriate capacitor value (C) that enables good power factor PF at system frequency. The circuit diagram of the STF and the impedance versus frequency curve of this filter is depicted in Fig (13).

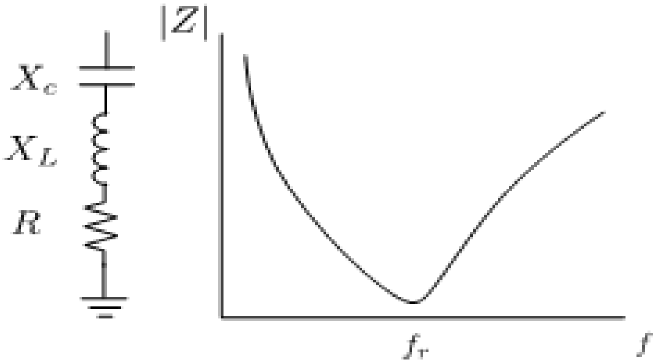

Fig. (13): The circuit diagram of the STF and The impedance versus frequency curve of the STF

6- Simulation results of the Stand Alone (PPF) for DCM

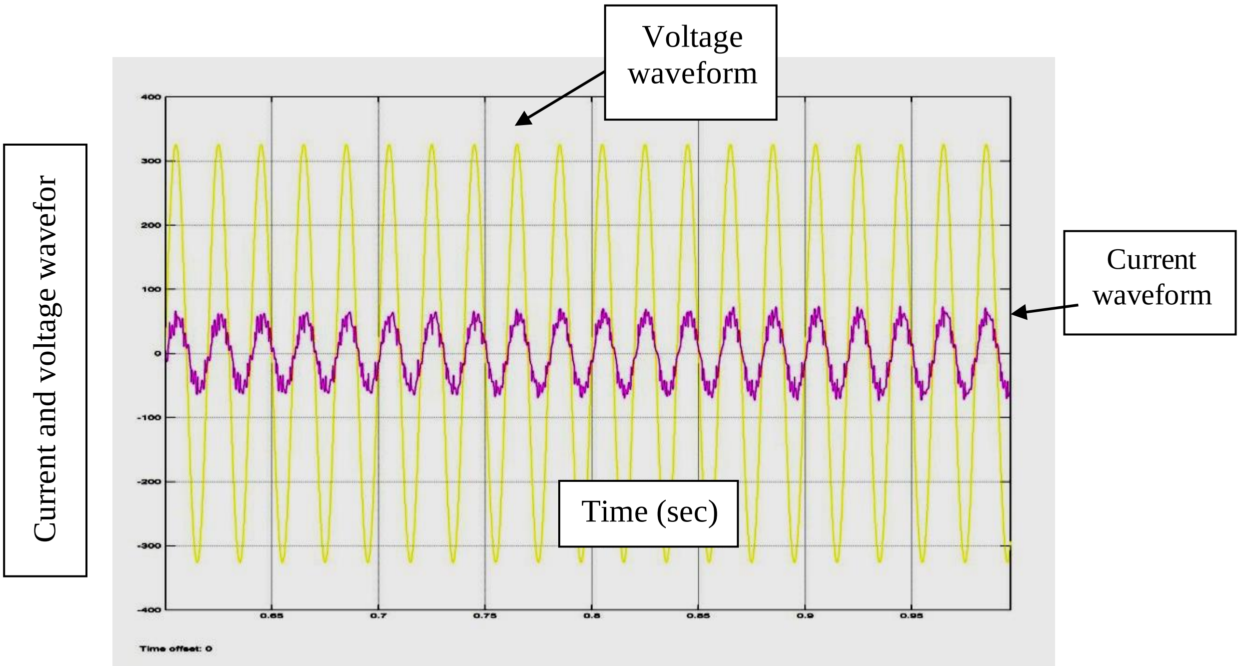

Fig. (14): the capability of PPF for PF correction

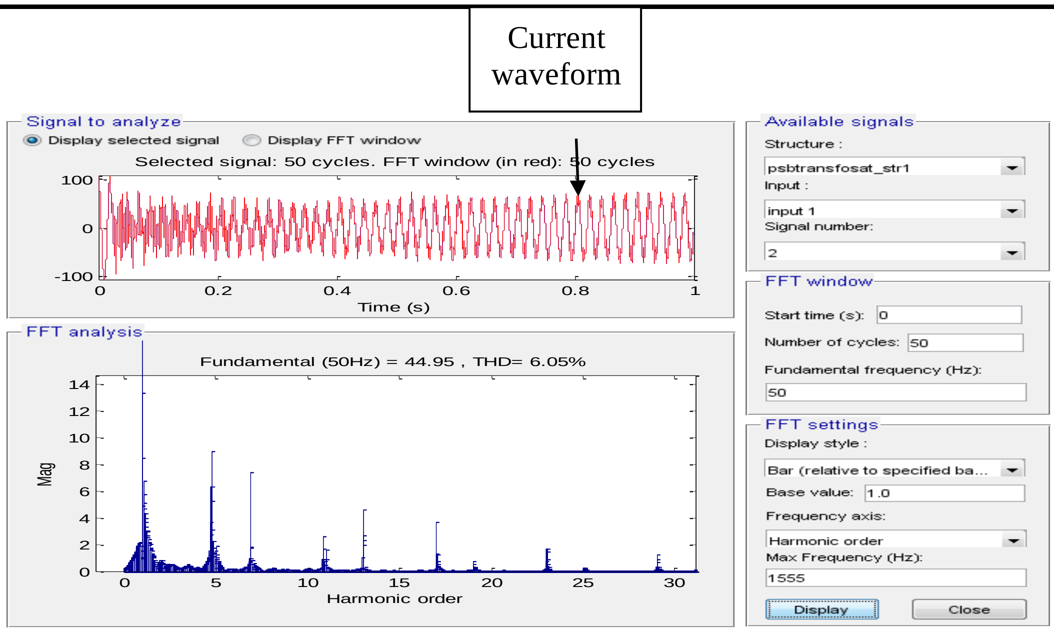

Fig. (15) :THD (i) for supply current waveform after connecting PPFs.

It is to be noted from the above simulation results for the current waveform in fig(14) and fig(15) and fig(11) that:

- Before connecting the PPFs only to the DCM drive:
  - The voltage waveform is sinusoidal
  - The current waveform is not sinusoidal. The harmonic supply current (THD (i) =35%)
  - The phase angle between supply voltage and supply current was approximately (62degrees (PF = 0.47).
- After connecting the PPFs to the DCM drive :
  - No changes in the waveform of supply voltages still the same.
  - the THD(i) of supply current is decreased from 35% to 6.05%.
  - the capability of the proposed shunt PPFs to improve the power factor for the system from 0.47 to 0.98.

Disadvantage for connecting the PPFs to the systems

- A separate filter is necessary for each harmonic frequency

- Large V.A rating for this filter as both the harmonic current and the fundamental frequency current flow into the filter .It has tuning problems and parallel resonance.

Other method of harmonic reduction is considered such as current injected by hybrid active Filter (HAPF) to overcome the above limitation.

1.7-Simulation results for pure APF in the DCM study case

Since the passive filter may increase the filter cost and it may cause resonance with the source impedance, so the effect of using the pure shunt APF will be studied.

Fig. (16) shows the source current and voltage waveform before and after connecting the pure shunt APF to DC drive.

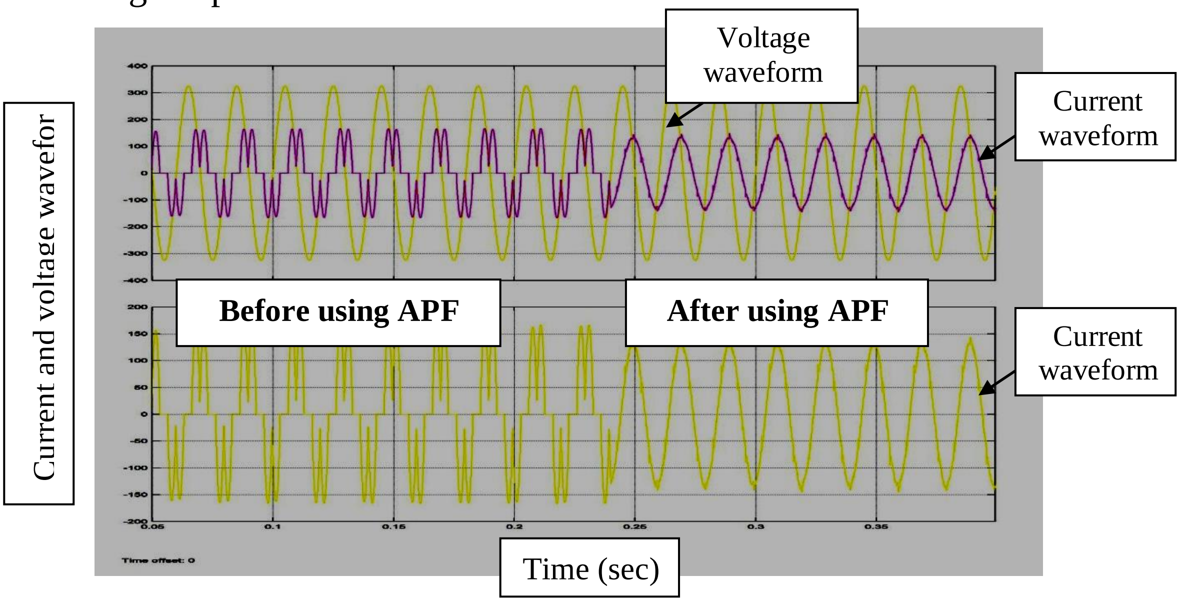

Fig. (16): The source current /voltage waveform before and after connecting the pure APF to DC drive

- ➢ It is to be noted from the above simulation results for the supply voltage and current in fig(16) and fig. (17) that:
- ➢ Before connecting the pure APF to the DCM
    - The source voltage waveform is approximately sinusoidal

- The source current waveform is not sinusoidal. The harmonic supply current (THD=35%).
- The phase angle between supply voltage and the supply current was approximately 62 degree (i.e. PF = 0.47).

After connecting the pure APF to the DCM drive.

- The THD present in the supply current waveform is decreased to 2.2% from 35%.
- The phase angle between the supply voltage and the supply current was approximately 68.4 degree(PF=0.37)

It can be concluded that:

❖ The pure APF has no effect on supply voltage waveform

❖ It can reduce the current distortion to the standard values

❖ It can't improve the power factor

From the above result and discussion the pure APF cannot give the good filtering performance, so that the passive filter must be added to obtain the good filtering and compensation.

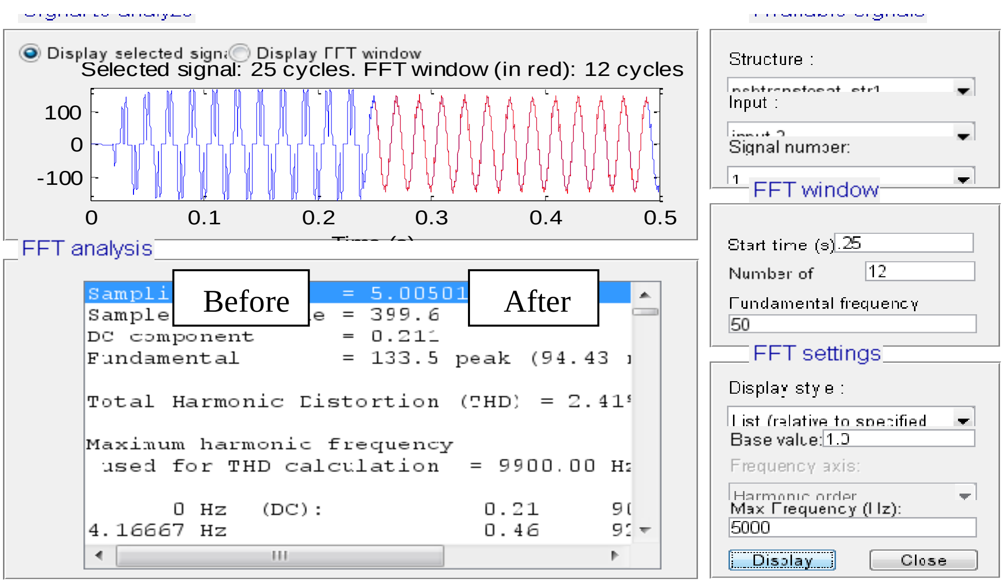

Fig. (17) shows the spectrum analysis of supply current before and after connecting the pure APF to the DC drive

8 -Simulation results using pure APF with passive filter (hybrid filter)

As shown in Fig. (18) the addition of the passive filter give good compensating results and the power factor become near to unity and fig (19) shows the possibility of hybrid filter to reduce the current distortion to the standard values about(3.1%) as shown in Fig. (19)

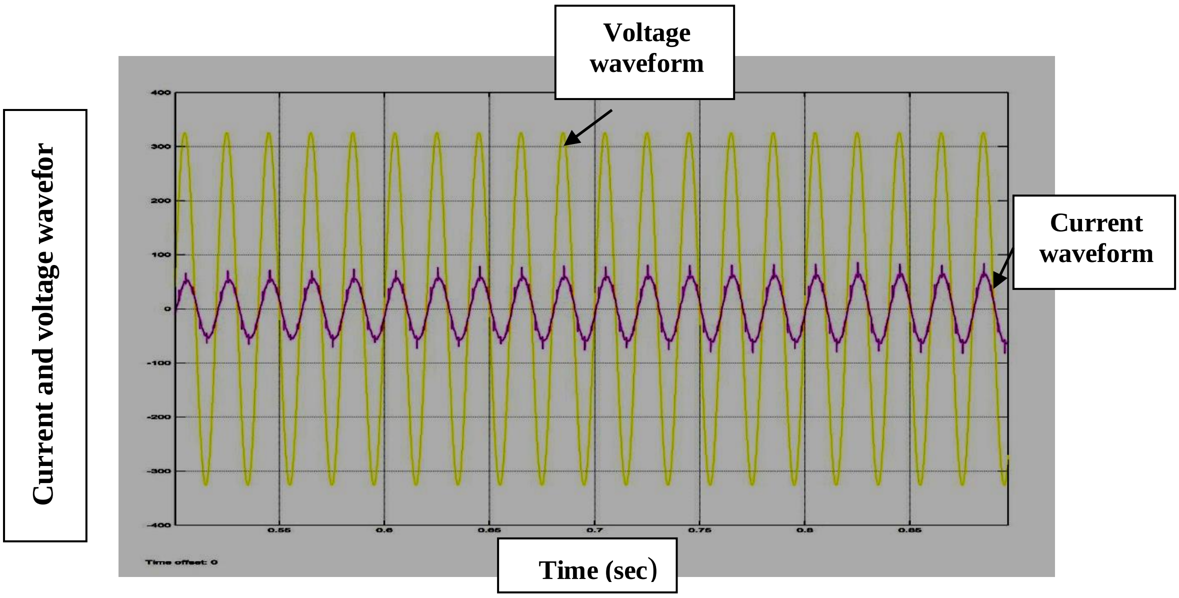

Fig. (18) show the phase angle between the supply voltage and the supply current after connecting hybrid filter.

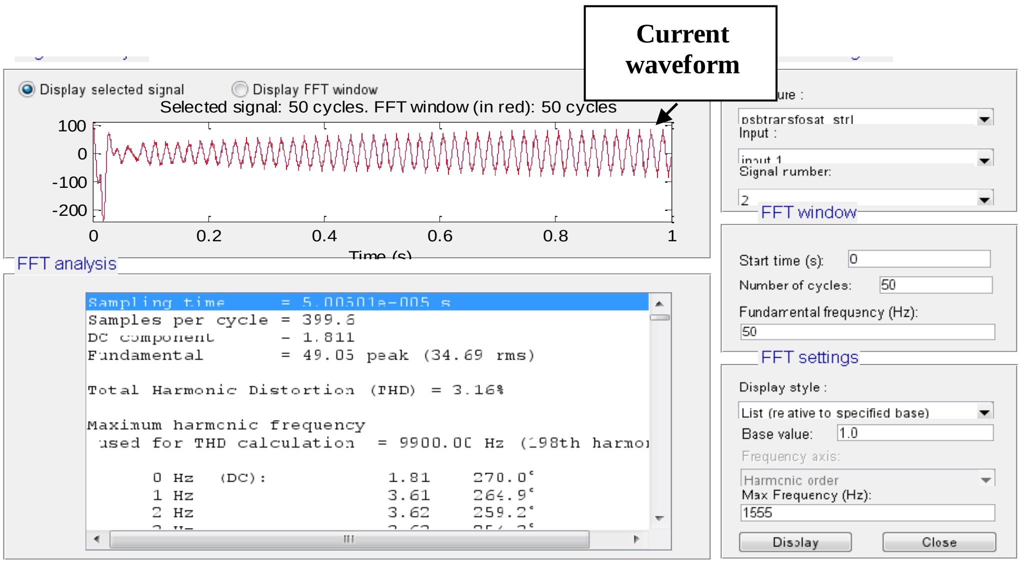

Fig. (19) shows the spectrum analysis of the supply current waveform after connecting the hybrid filter

9-Comparison of Results

As shown in Table (2) comparisons are made between 3study cases ,1- before compensation without using any filter,2- after using shunt **PPF**s and 3- after using pure **APF** and finally 4- after using hybrid filter **HAPF**.

Table (2) comparison results between the various method for power quality improvement

Comparison types Filter / Method	Without any Filter	With shunt PPFs	With shunt Pure APF	With shunt Hybrid filter
THDv % of supply Voltage	0.01	0.01	0.01	0.01
THDi% of supply Current	35.7	6	2.45	3.45
Power factor value	0.47	0.98	0.37	0.98

It is clear from the comparison of the simulation results that , the best choice for both compensation and harmonic mitigation is obtained using hybrid filter.

Conclusion

The APF without shunt passive filter in this study is only able to reduce the distortion in the source current waveform but cannot improve the power factor. In this papers a simulation for a standalone shunt passive filter with the DCM drive system to improve the power factor and reduce the current distortion. When comparing the performance of the proposed PPFs method and the proposed hybrid filter for this DCM drive, it can be concluded that . hybrid filter is more efficient for harmonic suppression and Power factor improvement . hybrid filter also responds very fast under changes in the load condition , compared to PPF.

References

[1] M.Z.EL-Sadeek, (2007). " Power System Harmonic Filters" , (book) , Mukhtar Press, Assuit,

[2] Raneru Nageswara Rao. (2013). "Harmonic Analysis of Small Scale Industrial Loads and Harmonic Mitigation Techniques in Industrial Distribution System" in IJERA, 3, 1511-1540.

[3] Manish Kumar Soni, Nisheet Soni. (2014). "Review of Causes and Effect of Harmonics on Power System" in IJSETR, 3 (2), 2278-7798

[4] Jarupula Somlal (2011)."Efficient Hybrid Shunt Active Power Filter For Improvement Of Power Factor And Harmonic Suppression Using Matlab" EEE Department Swarnandhra College Of Engineering& Technology Narsapur, 195.

[5] Francisco C .De La Rosa, (2006). "HARMONIC AND POWER SYSTEMS", Book, Taylor& Francis Group, LLC,.

[6] A.M. Munoz, (2007). "Power Quality Mitigation Technologies in a Distributed Environment", Book, Springer- Verlag London.

[7] Dan , S.G, Benjamin, D.D., Magureanu, R., Asminoaei, L.,Teodorescu, R.,and Blaabjerg, F., (2005). "Control Strategies of Active Filters in the Context of Power Conditioning ", European Conference on power Electronic and Applications , Dresden, pp. 10.

[8] Young, S.C., and Hanju, C., (2011). "A Single-Tuned Passive Harmonic Filter Design Using Transfer Function Approach for Industrial Process Application", International journal of Mechatronics and Automation, Volume 1, No. 2, pp.90-96,.

[9] Bula , D., and Pasko , M. , (2010). "Hybrid Power Filter with Single Tuned Passive Filter – Dynamical Properties", International School on No Sinusoidal Currents and Compensation pp. 80-83,.

الملخص العربي

تحسين جودة الطاقة الكهربائية لمغير سرعة محرك تيار مستمر في مصانع السكر باستخدام المرشح المختلط

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تعتبر ادارة جودة الطاقة الكهربائية المشكلة الرئيسية التى تواجه الصناعة اليوم, والتى تتأثر بشكل اساسى بالتوافقيات المتولدة فى الشبكة الكهربائية, هذا بالاضافة الى ان الاستخدام المتنامى اليوم لمغيرات السرعة بنوعيها (مغيرات السرعة لمحركات التيار المستمر والمتردد) يولد نسبة عالية من التوافقيات فى انظمة التوزيع نتيجة للتيارات الغير جيبية المسحوبة من الشبكة بواسطة مغيرات السرعة. ومن المتعارف علية جيدا ان افضل جودة للطاقة الكهربائية تحدث عندما تكون موجتى الجهد والتيار جيبية الشكل لكن هذا لا يحدث عمليا بسبب وجود تشوه فى شكل الموجة وهذا يعرف (تشوة بالتوافقيات), وعلى وجه العموم يوجد تشوه فى موجة الجهد من مصادر التغذية من الشبكة الحكومية المغذية لشبكة المصانع.

وعلى الرغم من ان استخدام الاجهزة الالكترونية ومغيرات السرعة فى الصناعة يعطى مرونة اكثر فى التحكم فى التشغيل ويوفر فى استهلاك الطاقة الا انه يتسبب فى تدهور جودة الطاقة نتيجة تشوه موجة التيار واستهلاك طاقة غير فعالة كبيره جدا تؤدى الى تدنى معامل القدرة للشبكة الكهربائية المغذية للمصانع. للحد من التوافقيات يتم استخدام المرشحات.

وهناك نوعان من المرشحات المستخدمة فى تقليل واخماد التوافقيات المتولدة فى الشبكة فيما تسمى بالمرشحات الفعالة والمرشحات الغير فعالة كلا يستخدم على حدة.

يقدم هذا البحث نموذج تصميم لمرشح قدرة قادر على التغلب على العقبات الناتجة من استخدام المرشح الفعال والمرشح الغير فعال كلا على حده ,وايضا قادر على اخماد التوافقيات وتحسين معامل القدرة وتقليل تكلفة استخدام الطاقة وذلك باستخدام المرشحات المختلطة(مرشح فعال مع مرشح غير فعال) .

وقد تمت فى النهاية مقارنة النتائج العملية مع نتائج المحاكاة على برامج الحاسب مما اظهر تشابه بينهما و اظهرت ان هذا المرشح المختلط له القدرةعلى تحسين معامل القدرة و اخماد التوافقيات والوصول الى قيم تحقق القيم القياسية و قد اجريت المحاكاة على مغير سرعة لمحرك تيار مستمر باستخدام برنامج الماتلاب 2010.