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PARAMETERS IDENTIFICATION OF A 3-PHASE LC FILTER USED FOR VARIABLE FREQUENCY DRIVE BASED ON PRACTICAL INDUCTION MOTOR TESTING

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ABSTRACT

A lot of harmonics exist inherently in the front end of 3-phase rectifier feeding Variable Frequency Drive (VFD) of 3-phase induction motor due to the nonlinearities behavior in such loads. The harmonics cause energy losses and deficiency to the overall system. The goal of this paper is to reduce the harmonics for a variable frequency drive by calculating the equivalent circuit of the 3-phase induction motor and identifying the parameters of a passive filter, which is connected to the input side for the rectifier from the VFD converter. The equivalent circuit for the 3-phase squirrel cage induction motor is achieved according to the results of laboratory tests. The concept of point of common coupling (PCC) is implied into the calculations of harmonics and power factor. The performance of the VFD described is simulated using Matlab /Simulink (2008).

KEYWORDS: Variable Frequency Drive, Passive Filter, Induction Motor, Harmonics, Point of Common Coupling.

تعريف ثوابث مرشح LC ثلاثي الطور يستخدم لسائق ذو التردد المتغير مستند على الاختبارات العملية للمحرك الحثي

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الخلاصة

ان الكثير من التوافقيات موجودة اصلاً في النهاية الامامية للمعدل الثلاثي الطور الذي يغذي السائق ذو التردد المتغير للمحرك الحثي ثلاثي الطور بسبب السوك اللاخطية في مثل هذه الاحمل. حيث تسبب التوافقيات في خسارة الطاقة و قلة كفاءة النظام بشكل عام. ان هدف هذه الورقة هو تخفيض التوافقيات للسائق ذو التردد المتغيّر بأحتساب الدائرة المكافئة للمحرك الحثي ثلاثي الطور و تعريف ثوابت المرشح الخامل الذي يربط الى جهة الادخال للمعدل من محولة السائق ذو التردد المتغير.

تم تحقيق الدائرة المكافئة للمحرك الحثي ثلاثي الطور ذو القفص السنجابي اعتماداً على نتائج الاختبارات المختبرية. ان مفهوم نقطة الازدواج المشتركة (PCC) اخذت ضمناً في احتساب التوافقيات و معامل القدرة.

أن أداء السائق ذو التردد المتغير الذي قد تم وصفه تمت محاكاته بأستخدام برنامج MATLAB / SIMULINK.

1. INTRODUCTION:

Variable Frequency Drives (VFDs) of an induction motor have grown rapidly in many applications in recent years. Variable frequency drives change the speed of motor by changing voltage and frequency of the power supplied to the motor and it is now more important for process plants due to its ruggedness and maintenance free long life. The main components of VFDs are shown in Fig.1.

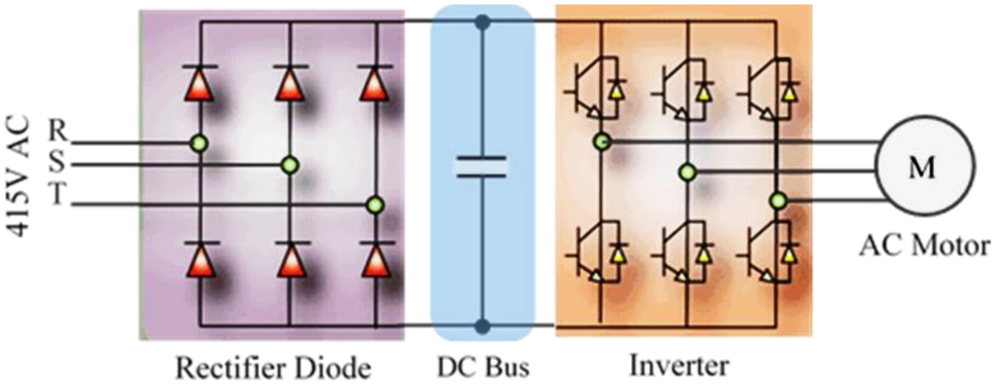

Fig. 1. Typical configuration of VFD with an induction motor.

The unfortunate side effects of use VFD are concerning production of harmonic distortion in the power system. These harmonics flows through power system and causing a lot of damage such as: distort in supply voltage, overloading of electrical distribution equipment such as transformers, decrease the system efficiency and other problems. The performance of VFD can be improved by several methods such as (appropriate selection of motor and design), utilization of a suitable control method and improving of the (input and output waveforms) of converter [1].

There are many researches have been done in the last years of performance improvement of VFD. However, Chaiyan (2012) proposed a novel optimization approach of a passive electromagnetic interface filter, using two-port network technique to reduce or minimize of noise in a three phase adjustable speed AC motor drive. Tamilvani, et. al. (2014) design and simulate shunt active filter for current harmonic reduction in variable speed drive based induction motor drive. Uma, et. al., (2013) design and simulation of a passive filter C-type and AC choke to mitigate harmonics and inter-harmonics at feeding of adjustable speed drives.

In this research, the performance improvement of a VFD is focused on reducing the harmonics in the system. The reduction in harmonics is achieved by calculating the equivalent impedance of an induction motor and parameters determination of a passive filter. Accurate calculations of the equivalent impedance for an induction motor and improving the input waveform to the converter, makes a reduction in harmonic currents and leads to minimizing of I^2R losses. The parameters of a three phase squirrel cage induction motor are calculated, according to the results of tests. The improvement of the input waveform of the converter is fulfilled by parameters determination of a low pass filter which is connected to the input side for the converter. Also, the calculations of the impact of power source and the feeding cable on the system are achieved according to the concept of point of common coupling (PCC) IEEE 519-1992 standards of harmonic current limits. The 6- pulse invertor, "Insulated Gate Bipolar Transistor" (IGBT) with a 5 kHz switching frequency and a pulse width modulation technique (PWM) are used in this design.

2. AC MOTOR ANALYSIS:

The suitable cost and ruggedness of the AC squirrel cage induction motor increase the desire to use it as electromechanical energy conversion means. There are many advantages to using this type of motors with VFDs systems such as: speed variation, heavy load inertia starting, (high starting torque requirements and low starting current requirements) etc. According to the above advantages the analysis of equivalent circuit of motor is much important to ensure the best performance [5]. In this research, the practical specifications to the three phase squirrel cage induction motor (type B) which analyzed are: 4-pole, 50 Hz frequency, 380 V, 5.5 hp, star connection, class F insulation, 1.15 service factor and 2% slip. The synchronous speed of the motor varies linearly with the frequency and inversely with the number of poles as follows:

$$N_S = \frac{120 \times f}{P} = 1500\ \text{RPM} \tag{1}$$

$$N_R = (1 - S)N_S = 1470\ \text{RPM} \tag{2}$$

Where, N_S is the synchronous speed, N_R is the rotor speed in (RPM) and f is the line frequency in Hz.
The parameters of the equivalent circuit of an induction motor can be determined experimentally according to the no-load test, the locked-rotor test, and measurement of the DC resistance of the stator winding. The results of three tests above as shown in Table 1.

Table 1. Results of the tests.

No load test f_1= 50 Hz	$V_{NL\ (L-L)}$ = 379.7 V	I_{NL} = 2.53 A	$P_{NL\ (3-ph.)}$ = 236 W
Locked-rotor test at f_1 =12.5 Hz	$V_{Lr\ (L-L)}$ = 30.1 V	I_{Lr} = 8 A	$P_{Lr\ (3-ph.)}$ = 324 W
The average dc stator winding resistance		0.28 Ω	

According to IEEE test code recommendations for locked-rotor test, use 25% from the rated frequency in this test (f_{test} = $0.25f_{rated}$). Variable voltage source is adjusted to obtain rated current of motor, to protect windings of motor from the excessive heat.
From locked-rotor test:

$V_{Lr} = \frac{V_{Lr\ (L-L)}}{\sqrt{3}} = 17.37\ \text{V}$ and $I_{Lr} = 8\ \text{A}$.

$\cos\theta_{Lr} = \frac{P_{Lr}}{3\times V_{Lr}\times I_{Lr}} = 0.777,\quad \theta_{Lr} = 34$ and $\sin\theta_{Lr} = 0.629$.

$$Z_{Lr} = \frac{V_{Lr}}{I_{Lr}} = 2.17\ \Omega/\text{phase} \tag{3}$$

$$R_{Lr} = Z_{Lr}.\cos\theta_{Lr} = 1.686\,\frac{\Omega}{\text{phase}} \tag{4}$$

From the no-load test, the stator resistance R_1 can be calculated as:

$$R_1 = \frac{\text{average dc stator resistance measurement}}{2} = 0.14\ \Omega/\text{phase}$$

Due to the skin effect, the value of stator resistance increasing to 5% with use 12.5 Hz.

So, $R_1 = 0.14 \times 1.05 = 0.15\ \Omega/\text{phase}$

$R_2' = R_{Lr} - R_1 = 1.54\ \Omega/\text{phase}$

$$X_{Lr} = Z_{Lr}.\sin\theta_{Lr} = 1.3\ \Omega/\text{phase} \tag{5}$$

Reactance are calculated according to IEEE test code for leakage reactance ratios as Table 2.

Table 2. IEEE Test Code for Empirical Ratios of Leakage Reactance [7].

Reactance ratio	Squirrel-cage: Design class A	B	C	D	Wound rotor
$X_1/X_{L.\,r}$	0.5	0.4	0.3	0.5	0.5
$X_2/X_{L.\,r}$	0.5	0.6	0.7	0.5	0.5

For a National Electrical Manufacturers Association (NEMA) motor design, the reactances can be calculated for class B motor as: $X_1 = 0.4\ X_{L.\,r} = 0.52\ \Omega$ / phase, $X_2 = 0.6\ X_{L.\,r} = 0.78\ \Omega$ / phase.
The reactances were calculated in locked rotor test at 12.5 Hz, therefore the skin effect at 50 Hz is considered as 12.5%:

$$X_1 = \frac{X_{1\ \text{calculated}}}{12.5} \times f_{\text{reated}} = 2\ \Omega\ /\ \text{phase} \quad (6)$$

$$X_2 = \frac{X_{2\ \text{calculated}}}{12.5} \times f_{\text{reated}} = 3.26\ \Omega\ /\ \text{phase} \quad (7)$$

From No-Load test: The magnetizing reactance X_m, core losses (hysteresis and eddy current) r_c and combined core, friction and wind age losses can be calculated as:

$$V_{NL} = \frac{V_{NL\,(L-L)}}{\sqrt{3}} = 219.2\ \text{V and } I_{NL} = 2.53\ \text{A.}$$

$$\cos\theta_{NL} = \frac{P_{NL}}{3 \times V_{NL} \times I_{NL}} = 0.142, \quad \theta_{NL} = 81.84 \quad \text{and} \quad \sin\theta_{Lr} = 0.98.$$

$$Z_{NL} = \frac{V_{NL}}{I_{NL}} = 86.5\ \Omega/\text{phase} \quad (8)$$

$$R_{NL} = Z_{NL} . \cos\theta_{NL} = 12.3\ \Omega/\text{phase} \quad (9)$$

$$r_C = R_{NL} - R_1 = 12.14\ \Omega$$

$$X_{NL} = Z_{NL}\ \sin\theta_{NL} = 84.7\ \Omega/\text{phase} \quad (10)$$

$$X_m = X_{NL} - X_1 = 82.6\ \Omega/\text{phase} \quad (11)$$

According to the exact equivalent circuit of the motor, the equivalent impedance can be calculated as:
The rotor impedance (Z_2) is:

$$Z_2 = R_2 + R_2 \frac{1-S}{S} + jX_2 = 1.8 + j\ 0.78\ \Omega/\text{phase}$$

The magnetizing impedance (Z_m) contain on the core losses branch (r_c) parallel with a branch of magnetizing reactance (X_m), That can be calculated as:

$$Z_m = r_C\ //\ j\ X_m = 2.42 + j\ 12.1\ \Omega/\text{phase}$$

The equivalent impedance (Z_{ab}) for the rotor impedance (Z_2) and the magnetization impedance (Z_m) is: $Z_{ab} = Z_2\ //\ Z_m = 5.7 + j\ 0.87\ \Omega/\text{phase}$. Now, the equivalent impedance (Z_{eq}) of the induction motor is:

$$Z_{eq} = Z_1 + Z_{ab} = 6 + j\ 1.4\ \Omega \quad (12)$$

Now, the friction, windage, and core loss are calculating combined as:

$$P_{N.L} = 3\ I_{N.L}^2 . R_1 + P_{Core} + P_{f,\ w}$$

$$P_{Core} + P_{f,\ w} = 233\ W \quad (13)$$

Full-load shaft power (P_{sh}) equel to (4103 W). The mechanical power developed (P_m) can be calculated as:

$$P_m = P_{sh} + P_{Core} + P_{f,\ w} = 4336\ W \quad (14)$$

$$P_g = \frac{P_m}{1 - S} = 4424.5\ W \quad (15)$$

Rotor copper loss are $P_{cu2} = S.P_g = 88.5\ W$, and $\omega_S = \frac{2\,\pi\,N}{60} = 157\ rad.\frac{-1}{s}$.

$$T_e = \frac{P_g}{\omega_S} = 28.2\ N.m \quad (16)$$

Where, (P_g) the air gap power, (ω_s) synchronous angular velocity of the rotor and (T_e) the electromagnatic torqe. The calculations results of the motor as shown in the Table 3.

Table 3. The calculation results of the AC induction motor.

P_{in} (W)	$P_{T\ Loss}$ (W)	P_g (W)	P_{out} (W)	T_e (N.m)	η %
4427.4	324.3	4424.5	4103	28.2	92

Where, ($P_{T\ Loss}$) is the total losses of the motor and (η) is the motor efficiency. However, when an inverter apply a distorted voltage to the motor due to bridge operation. The core losses will be increased because, the total field mixed with the fundamental rotating fields and harmonic fields. Therefore, the hysteresis losses will increased with increasing the frequency as well as, the eddy current losses will be increased with a square of the frequency. Furthermore, the harmonic currents will produce additional (I^2.R) losses in the motor winding [5]. Therefore, there are many considerations must be taken into account to select of the motor which will be used in VFDs such as: low stator resistance, a low rotor resistance, the motor insulation class and 1.15 service factor. These factors are very important especially when the motor running in low speed to overcome overheating [6, 7].

3. POWER SUPPLY MODEL FOR VSD:

The assessments of harmonic distortion are usually performed at a point between the end of customer or multiple electrical loads may be connected at the electrical system. This point is known as a point of common coupling (PCC). According to IEEE-519, this point must be accessible to both of utility and the customer for direct measuring purpose. For the industrial and commercial usages, the location of PCC is usually at the primary winding of the service transformer supplying the facility [8]. Therefore, the equivalent circuit of the variable frequency drives and a power supply system are considered as in Fig. 2.

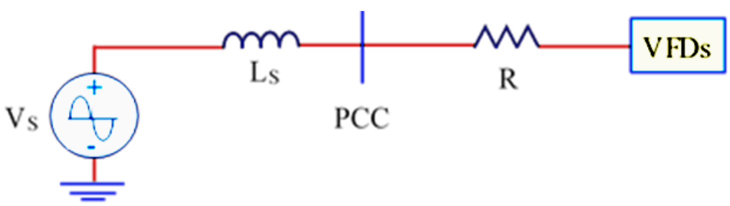

Fig 2. Equivalent circuit of a VFDs power supply circuit.

Where, (L_s) represents the inductance for the source (transformer) and (R) represent resistance of the source and the feeding cable. The calculation of the transformer impedance is very important step to observe the effect of the source in harmonics generating. The parameters of transformer are taken from the data sheet of practical transformer as: 3-Ph, 50 Hz, 1500 kVA, 415 VAC (line to line) secondary, 10% impedance, X/R ratio is 7. The transformer impedance can be calculated from the percent impedance Z_{tr}. as in eq. 17.

$$Z = R_{tr} + j\, X_{tr} = \left(\frac{V^2}{AV_{3-Ph}}\right) \times Z_{tr}(\%) \tag{17}$$

$$Z = \frac{415^2}{1500 \times 10^3} \times 0.1 = 11.5\ m\Omega \tag{18}$$

Where: $VA_{3\text{-}Ph}$ is VA rating of the transformer, Z transformer impedance, R_{tr} is the resistance of transformer, X_{tx} is the reactance of transformer and V is phase-to-phase voltage source.

$$|Z| = \sqrt{{R_{tr}}^2 + {X_{tr}}^2} \tag{19}$$

X_{tr} / R_{tr} =7. Therefore, R_{tr} = 1.66 mΩ and X_{tr} = 11.62 mΩ. So, the transformer inductance is:

$$L_{tr} = \frac{X_{tr}}{\omega} = 0.037\ mH \tag{20}$$

Moreover, the resistance of the cable can be calculated according to the list of current carrying capacity. The Choice of cable size is according to the full load current, where the cross sectional area for the cable is (16 mm^2). In this research, the length of the cable which connects the supply terminals with the rectifier was assumed to be (30 m) to avoid the effects of electromagnetic interference with a transformer. The resistance of the cable can be calculated as in eq. 21:

$$R_C = \rho \frac{l}{A} = 34.7\ \Omega \tag{21}$$

Where, (ρ = 0.01851 Ωmm^2 /m) is the resistivity for copper cable material, (l) the length of the conductor in meters and (A) presents the cross section area of conductor in mm^2. The calculated results of source impedances of the system shown in the Table 4.

Table 4. Parameters of the source (transformer).

Impedance of Transformer (Ω)		**Resistance of Cable R_C (mΩ)**
R_{tr} (mΩ)	**L_{tr} (mH)**	
1.66	0.037	34.7

4. HARMONICS AND POWER FACTOR ANALYSIS:

Any waveform which is not sinusoidal (complex) can be shown to contain sinusoidal waveforms of integer multiples of the fundamental. In a 50 Hz electrical system, 150 Hz is the 3^{rd} harmonic, 250 Hz is the 5^{th} harmonic etc.

The orders of significant harmonics current which will be generated in system are n = K q ± 1. Where: n is the significant harmonic order, k is any positive integer (1, 2, 3, etc.) and q the rectifier pulse number [9, 10]. According to the type of rectifier used, there are many odd harmonics will be generated such as: (5^{th}, 7^{th}, 11^{th} and 13^{th}, etc.). The harmonic components of the system are computed without filter, using (FFT) available in the Matlab program as shown in Fig. 3.

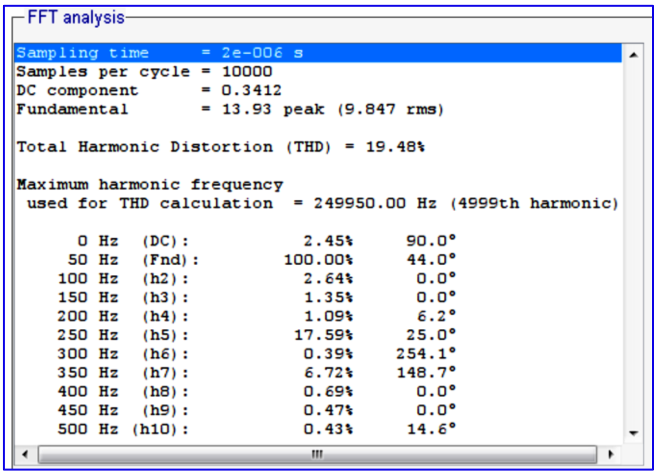

Fig. 3. Harmonics of inputs current (without filter) (FFT results).

According to (FFT) analysis, the input current and power factor can be calculated as follows: The fundamental maximum input current ($I_{1\ max.}$ = 13.93 A) and the (R.M.S) value of fundamental input current ($I_{1\ (r.m.s).}$ = 9.847 A). The THD of input current = 0.1948.

$I_{n\ r.m.s} = I_{1\ (r.m.s)} \times THD = 1.92\ A$

$$I_{in} = \sqrt{{I_{1\ (r.m.s)}}^2 + {I_{n\ (r.m.s)}}^2} = 10.03\ A \qquad (22)$$

The displacement angle or displacement factor $(\theta_1) = 44^o$, as illustrated in Fig. 3 from (FFT) analysis. Now the displacement power factor is:

$DPF = \cos\theta_1 = 0.72$, So $TPF = DPF \times \sqrt{\frac{1}{1 + THD^2}} = 0.706$

Where, ($I_{n\ r.m.s}$) is the (R.M.S) value of harmonic current, (I_{in}) is the (R.M.S) input current and (TPF) is the input power factor.

5. PARAMETERS DETERMINATION OF THE FILTER:

Passive filter techniques are one of the most common methods which are used to control the harmonic distortion in industrial applications. In this design, a low-pass filter was achieved. The line reactor must be calculated as a first step for the filter design. Where the line reactor provides an impedance to reduce the harmonics produced by nonlinear loads, it is similar to the function of an isolation transformer but with a smaller size and lower cost. An input AC reactors standard are; (either 1.5%, 3% or 5%, 7.5% impedance). Therefore, the percentage impedance for the reactor represented as in eq. 23.

$$\%\ impedance = \frac{\sqrt{3} \times I_{fun.} \times 2\pi \times f}{V_{L-L}} \times 100 \qquad (23)$$

According to the different types of front ends for input rectifiers, guidelines for harmonic voltage and current limitations for IEEE 519-1992 standard. A %5 impedance value is selected to add for the system with $I_{1\ (r.m.s)}$ or $I_{fun.}$ = 9.847 A.

5.1. The inductance calculation for low pass filter:

The AC Reactors are used to absorb the power line disturbances during the variable speed controllers or other sensitive equipment. It is used as a harmonic compensator and to get the optimum performance in the presence of harmonics [11, 12]. Anyway, calculating the inductance for the reactor as in eq. 24.

$$L_R = \frac{\%\,\text{impedance} \times V_{L-L}}{\sqrt{3}\times I_{fun.} \times 2 \times \pi \times f \times 100} = 0.387\ \text{mH} \quad (24)$$

After installing 5% line reactors, the THD becomes 10.06%, comparison with the previous THD 19.48%. The value of fundamental maximum input current according to (FFT) of simulation result is ($I_{1\ max.}$ =38.24 A) and the (R.M.S) value of fundamental input current ($I_{1\ r.m.s.}$ = 27.04 A). So, the ($I_{n\ r.m.s}$) and the (I_{in}) are calculated as in eq. 22.

$$I_{n\ r.m.s} = I_{1\ (r.m.s)} \times THD = 8.84\ A,\ \ I_{in} = \sqrt{{I_{1\ (r.m.s)}}^2 + {I_{n\ (r.m.s)}}^2} = 28.45\ A$$

The total harmonic distortion of the input current in a power system should reach to the limits of (IEEE519-1992 standard). The calculation of maximum short circuit current (I_{sc}) at PCC as in eq.25:

$$I_{S.C} = \frac{V_{L-L}/\sqrt{3}}{\omega_1\, L_{tr}} = 19.076\ \text{kA} \quad (25)$$

And for this, the ratio between $I_{s.c}$ to I_L as: $I_{s.c}$ / I_L = 702.6. Where, (ω_1) is the fundamental angular frequency and assuming (I_L= I_{fun} = 27.04 A) the maximum load current (fundamental frequency component ($I_{fun.}$) at PCC according to guidelines for IEEE 519. Anyway, the harmonic current limitation must be not exceeding 15 %. The total harmonic distortion for the load 27.5 kW must be limited to 15%. The THD must reduce for less than 15 percent (IEEE-1992 standard). According to previous rule, value of inductance must increases to the new value 5.805 mH.

5.2. Capacitance Calculation for a Low Pass Filter:

By selecting the value of the inductance 5.805 mH, displacement angle (θ_1) becomes (32.7^o); therefore, the displacement power factor is equal 0.84. Now by adding the power factor correction capacitors in the front of the rectifier, a low-pass passive filter is identified. The importance of adding capacitive reactance in a supply of needed VARs to improve the power factor from, TPF_1 (for θ_1) to TPF_2 (for θ_2). The simulation results for L_{f1} = L_{f2} =L_{f3} = 5.805 mH, as in the Table 3.

Table 3. Simulation results for Lf1 = Lf2 = Lf3 = 5.805 mH.

θ_1	THD %	DPF	TPF	Vd.c
19.7^o	6.12	0.94	0.80	390

In this design, the desired value of the true power factor (TPF) is 97 %, the $\boldsymbol{\theta_1}$ = 19.7^o, from Table 3. Now, the calculation of the distortion factor ($D_{Fact.}$), depends on the new THD value as in eq. 26.

$$D_{Fact.} = \sqrt{\frac{1}{1+THD^2}} = 0.981 \quad (26)$$

$$DPF_2 = \frac{TPF}{D_{Fact.}} = 0.988$$

The displacement angle (θ_2) equal $\cos^{-1}(0.988) = 8.89^o$. Where, P =$V_{d.c}^2$/ R = 27.5 kW. Therefore, Q = P (tan (θ_1) – tan (θ_2)) = 5 .545 kVAr; and the capacitive reactance is:

$$X_{C1} = \frac{3\,V^2}{VAR_s} = 31.1\ \Omega \qquad (27)$$

Where, (V) is the line to neutral voltage (rated voltage of capacitor) equal 240V. Now, value calculation of filter capacitance as in eq. 28:

$$C = \frac{1}{2\ \pi\ f \times XC_1} = 102.4\ \mu F \qquad (28)$$

According to the above calculation, the capacitances of the low-pass filter are: $\mathbf{C_{f1}}=\mathbf{C_{f2}}=\mathbf{C_{f3}}=$ 102.4 μF. The cutoff frequency of low-pass filter with (**L**=5.805 mH), as in eq. 29.

$$f_o = \frac{1}{2\,\pi\,\sqrt{L\ \times C}} = 204.8\ Hz \qquad (29)$$

The value of cutoff frequency equal 4.1 times from fundamental frequency 50Hz. Therefore, the resonant frequency is fewer than of 5^{th} harmonic current [13].
Now, the input line current of rectifier is calculated after filter correction as in eq. 30.

$$I_{Lf1} = \frac{P}{3 \times V \times TPF} = 40.82\ A \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (30)$$

The results of calculations and simulation for the system are summarized in the **Table 4**.

Table 4. Calculation and simulation results.

θ_1	THD %	DPF	TPF
11.8^o	2.81	0.97887	0.978

6. SIMULATION OF THE VFD RESULTS:

In this research, the Matlab ‘Simulink’ is used for carrying out the simulation and analysis of the waveforms. Where, the parameters of simulation used are: discrete simulation type and $2e^{-6}$ time of sampling in second.
However, the results which obtained in this design are compared with the results illustrated in [4]. Several parameters are compared such as: THD, power factor and other factors related to both of the design styles. A complete circuit of VFD with passive input filters as shown in Fig. 4.

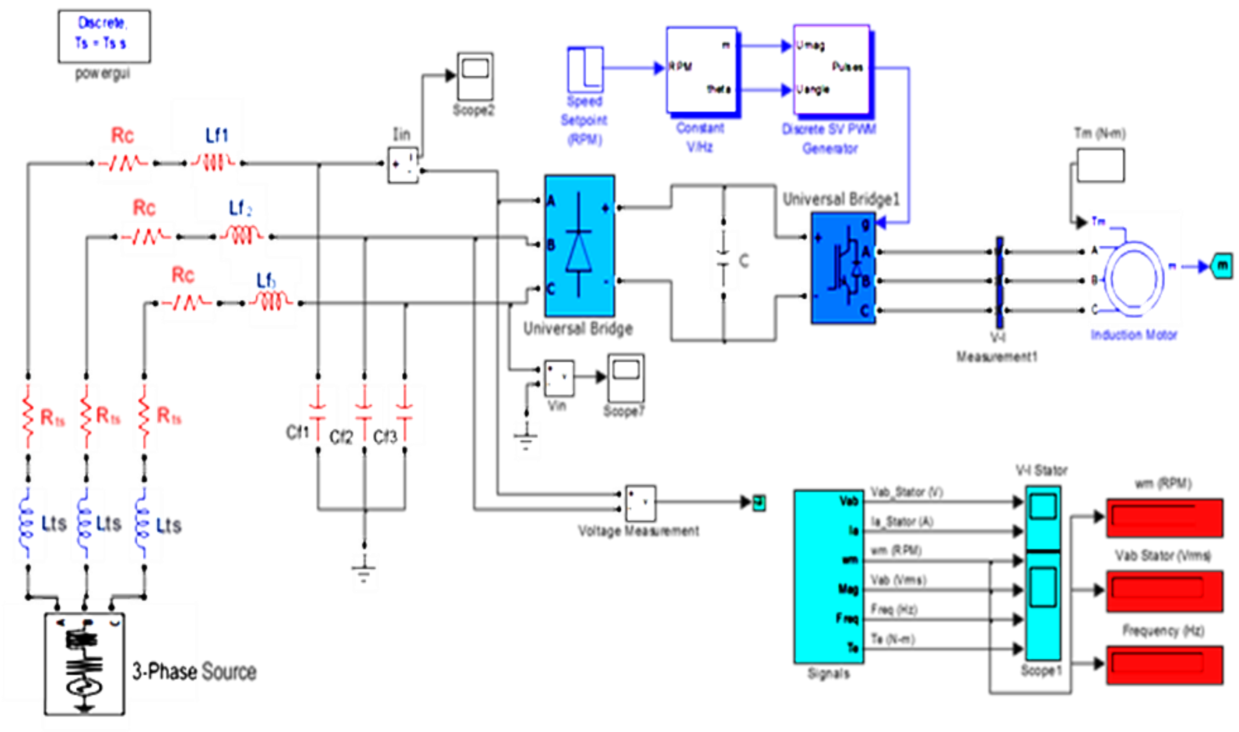

Fig. 4. Circuit diagram of VFD with filter.

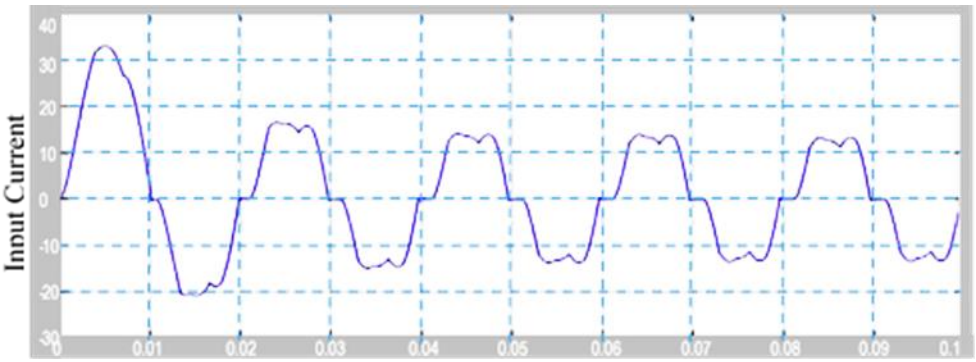

Fig. 5. Waveform of Input Current (Ii) for rectifier without filter for [4].

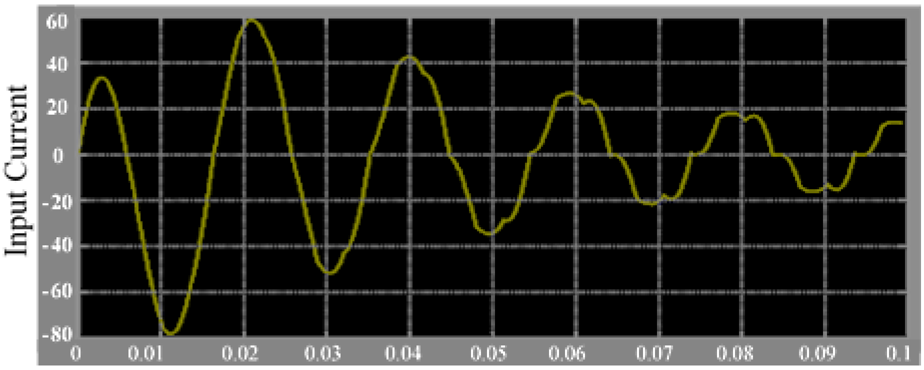

Fig. 6. Waveform of Input Current (Ii) for rectifier without filter for the proposed system.

As shown in Fig. 5, the peak value of input current to the rectifier is equal to 18A. While the peak value of input current which obtained from the rectifier is as shown in Fig. 6; equal to 60A. The difference in values and the form between two figs; because the nature of the source parameters, which is presented for the proposed system.

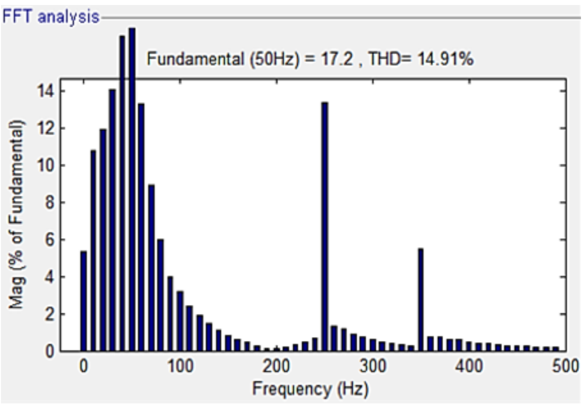

Fig. 7. THD analysis for input current of rectifier without filter for [4].

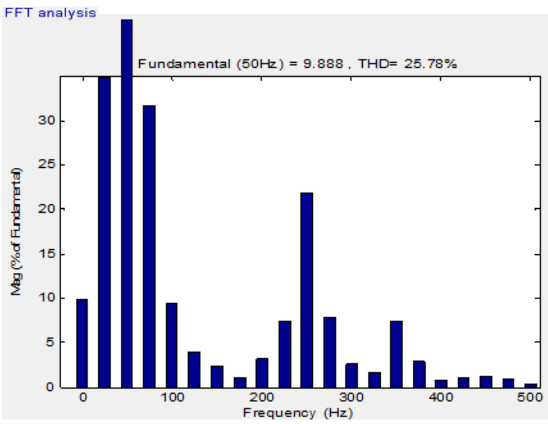

Fig. 8. THD analysis for input current of rectifier without filter for the proposed system.

As shown in Fig.7; the value of THD for input current rectifier without filter is equal to 14.91%, this value is small if compared with the result obtained in the Fig. 8; where the value of THD for input current rectifier is equal to 25.78%. This is due to the impact of transformer parameters and cable feeding who taking into account in the system of the proposed system, this made the system more practical.

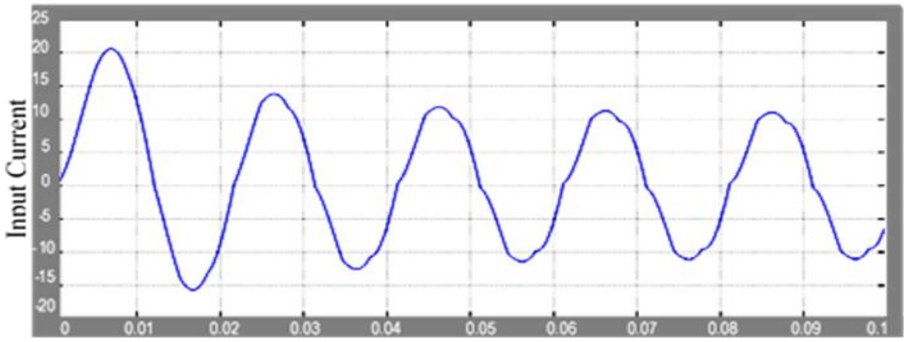

Fig. 9. Waveform of Input Current (Ii) for rectifier with filter for [4].

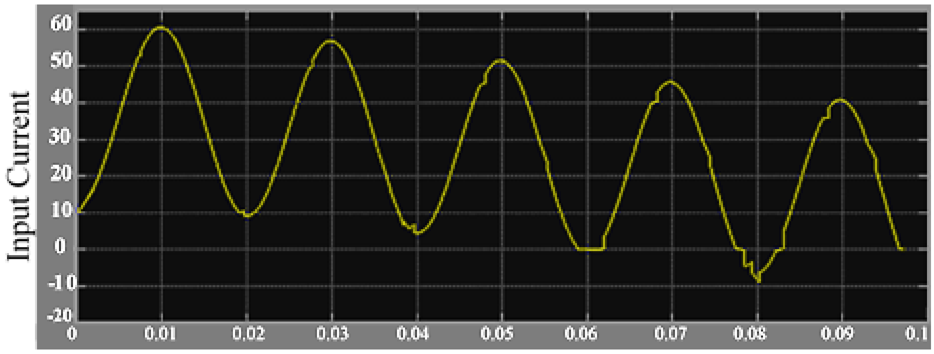

Fig. 10. Waveform of Input Current (Ii) for rectifier with filter for the proposed system.

As shown in Fig. 9, the peak value of input current to the rectifier with filter is equal to 14.5A. While the value of input current which obtained of the rectifier as shown in Fig. 10; equal to 58.5A.

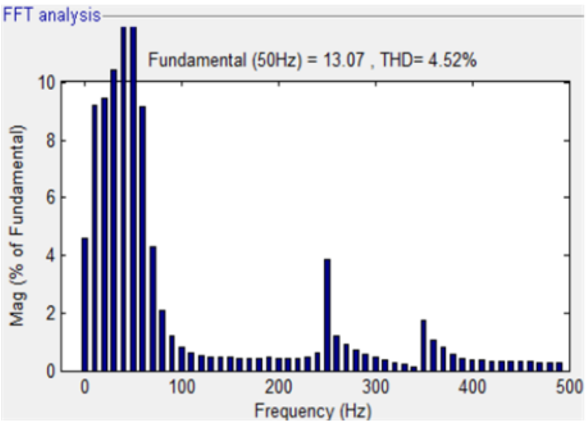

Fig. 11. THD analysis for input current of rectifier with filter for [4].

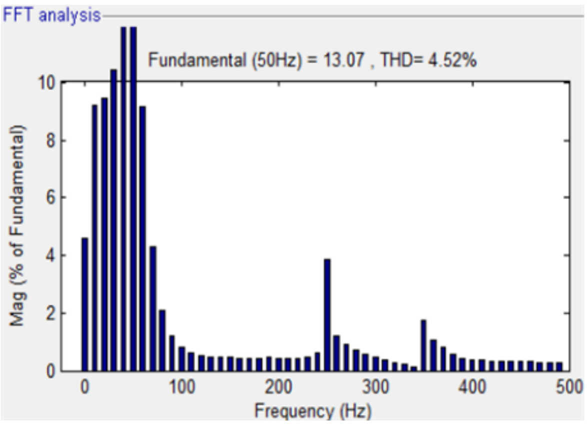

Fig. 12. THD analysis for input current of rectifier with filter for the proposed system.

The value of THD for input current rectifier with the filter is equal to 4.52%, as shown in Fig. 11. While the obtained value for THD is equal to 2.92%, as shown in Fig. 12. This value is better compared to the result in [4].

The comparison between specifications of the simulation for the proposed system and simulation specifications of [4] is shown in the Table 5.

Table 5. The comparison between specifications of the simulation.

	Input Voltage (V)	Line Frequency (Hz)	Motor Rated Power (h.p.)	Motor Speed (r.p.m)
Proposed system	**415**	**50**	**5.5**	**1500**
Design in [4]	**220**	**50**	**3**	**1200**

7. CONCLUSION:

In this paper, a passive filter parameter was defined to improve the VFD for power quality terms. Results in-terms of THD and P.F of the system show that the proposed system, THD equals to 2.92%, while research [4] THD equals to 4.52% and the P.F in the proposed system equals to 0.98 while research [4] P.F equals to 0.91. Determining the equivalent impedance for the motor being tested plays a viable role in determining the parameters of the filter which has a great deal of impact in performance improvement of the VFD, through reduction of harmonics.

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