Received: 18 April 2017 | Revised: 23 May 2017 | Accepted: 1 Jun 2017

DOI: 10.37917/ijeee.13.1.10 | Vol. 13| Issue 1 | June 2017

Open Access

Iraqi Journal for Electrical and Electronic Engineering

Original Article

Mathematical Driving Model of Three Phase, Two Level Inverter by (Method of Interconnected Subsystem)

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Abstract *In this paper describe to mathematical analysis for a three-phase, two level inverter designs. As we know the power electronic devices (inverter) to convert the DC power to AC power (controller on output voltage and frequency level). In Industrial applications, the inverters are used for adjustable speed (AC Drives). In this paper, the mathematical analyses for inverter design are done by using Software packages C++ Builder and visual C++ Language. For non- linear distortions described by the load power factor in power system networks. The P.F is reverse proportional with the harmonics distortion. Small P.F means much more of harmonic distortion, and lower power quality for consumers. to improve the P.F, and power quality in this paper the small capacitor installed as part of the rectified the load current has power (30 KW with P.F load 0.8), the fluctuations of the rectified voltage must not greater than +/- 10%.The power factor proportion of the load power, with Modulation coefficient p.u approximately unity. The calculation is achieved with different integrations steps with load power 30KW, 0.8 P.F. all results done Based on model and experimental data..*

***Keywords*:- Mathematical analysis, Modeling, three phase - two level inverter, Interconnected Subsystem.**

I. Introduction

This Paper describes a model of PWM inverter fed three-phase load. The model needs to be based up by decomposition of a system into sub circuits that are coupled by means of dependent voltage/current sources. Such an approach ensures high flexibility in construction of system models along with acceptable accuracy of computation based on model and experimental data, this model described is built up on decomposition of complex system into sub circuits interconnected via dependent voltage/current sources [1]-[2].To highlight this method of computer model construction we shall consider the simplest system with two-level converter and three phase loads (30, 100) KW show on in fig (1)..Computer models of the system with load power of 30 KW and semiconductor converters (SC) are widely used to facilitate development.

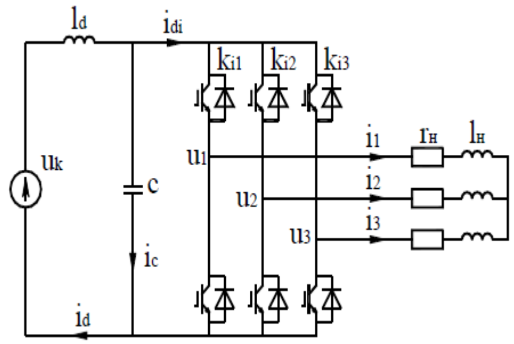

Figure 1 Scheme of the system with two-level inverter and load [3].

This system is decomposed into SC sub circuit and three-phase load block. SC is fed by current from a DC source with resistor and inductance in a circuit of rectified voltage there is a capacitor C with current. Each leg of SC consists of a transistor along with its anti parallel diode. Transistors and diodes are supposed to be ideal gates. The static energy losses are taken into account by resistor [4]. States of semiconductor elements are described by a discrete function kin, n=1, 2, 3: if an open transistor or diode connects n-the phase to a positive pole of the capacitor C then kin=1, and if it connects n-the phase to a negative pole then kin = 0. The transistors in an arm are complementary one to the other: if one transistor in an arm is fired, then the other is turned off. The arms of the bridge attached to the positive pole transfer input current of the inverter circuit, this source further.[5]-[6]

II. MATHEMATICAL ANALYSIS FOR THREE PHASE TWO LEVEL INVERTER [7].

The dividing mathematical analysis system into sub circuit, interconnected-dependent voltage , and current sources. As a result represented sub circuit shown in Fig 2.

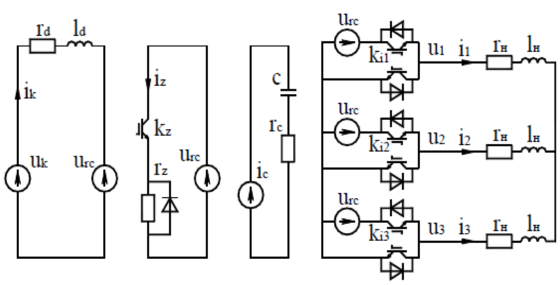

Figure 2 Dividing sub scheme of the system with two-level inverter and load.

Equivalent EMF Phase Inverter:

$$e_n = k_{in} u_{rc} \qquad (1)$$

Further transformation schemes shown in Fig.3.

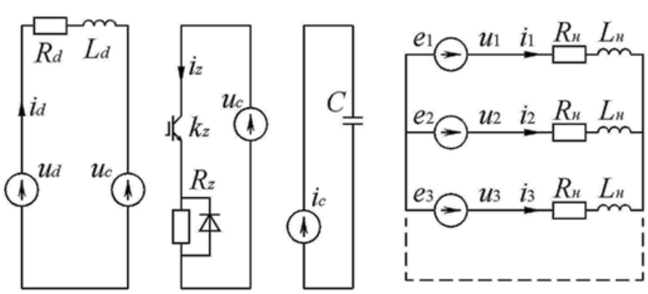

Figure 3 Transformation schemes system with two-level inverter and load.

Removal from the EMF phases of the zero sequence components.

$$e_0 = (e_1 + e_2 + e_3) / 3 \qquad (2)$$

$$u_n = e_n - e_0, \quad n = 1,2,3$$

Voltage of capacitor C:

$$u_c = \frac{1}{c}\int i_c dt$$

(3)

Output phase voltage of ideal converter without zero-sequence component:

$$e_n = k_{in} - \frac{k_{i1} + k_{i2} + k_{i3}}{3} u_{rc}, u_n = e_n \qquad (4)$$

DC voltage source current id is determined from an equation:

Derivative current supply:-

$$\frac{d_{in}}{dt} = \frac{u_n - r_n i_n}{l_H} \qquad (5)$$

Currents of bridge arms:

$$i_{in} = k_{in} \quad i_n \quad i_{in+3} = (k_{in} - 1) i_n, \quad n = 1,2,3 \qquad (6)$$

Transistor currents itn and diodes currents idn:

If $i_{tn} > 0, \quad m_0 i_{tn} = i_{in}, \ i_{dn} = 0$

$i_{tn} = 0, i_{dn} = -i_{in}$

when $n = 1,2,.....,6$

Inverter input current:

$$i_{dn} = i_{i1} + i_{i2} + i_{i3} \qquad (7)$$

DC voltage source current id is determined from an equation:

$$\frac{d_{ik}}{dt} = \frac{u_k - u_{rc} - r_d i_k}{l_d} \qquad (8)$$

Where i_z current of the protection circuit:

$$i_z = k_z \frac{u_{rc}}{r_z} \qquad (9)$$

The arms of bridge currents:

$$i_z = k_{in} i_n, \quad i_{in+3} = (1 - k_{in}) i_n \qquad (10)$$

Current of capacitor:

$$i_c = i_d - i_z - i_{di} \qquad (11)$$

III. Modeling of Control System Inverter

In modeling, circuit Fig.1. saw tooth voltage is described by the equation (12).

$$T_{on} = T_{on} + f_{on}.\Delta t \quad (12)$$

$$if \quad \tau_{on} > \frac{1}{2}, \qquad \tau_{on} = \tau_{on} - 1$$

$$u_{on} = 4 \mid \tau_{on} \mid -1$$

Where f_{on} frequency of the reference voltage Hz ,τ_{on}intermediate variable , Δt The second calculation.

Voltage control is determined by the following formulas:

$$t = t + \Delta t_y \quad (13)$$

$$u_{y1} = u_{y\max} \sin(\omega_H t) \quad (14)$$

$$u_{y1} = u_{y\max} \sin(\omega_H t - \frac{2\pi}{3}) \quad (15)$$

$$u_{y1} = u_{y\max} \sin(\omega_H t - \frac{4\pi}{3}) \quad (16)$$

Where t, time in second ω_H, angular frequency voltage reference load by rad/sec, Uy max the amplitude of maximum voltage control.

IV. Definition the Current Load Current by Instantaneous Values in Phases

In one of the possible construction of a control, system used PI controller acting load current. The actual operating current of three-phase load is determined in the process of calculating the instantaneous variables:

$$A = \frac{i_1^2 + i_2^2 + i_3^2}{3} \quad (17)$$

$$B = B + (A - B)\frac{\Delta t_y}{T_i} \quad (18)$$

$$I_\Phi = \sqrt{B} \quad (19)$$

A and B intermediate variables, T_i constant time aperiodic filter.

PI control at the load current:

$$\Delta I = I_Z - I, \; U_{ym} = U_{yi} + \Delta I \; .K_{I0} \quad (20)$$

If

$$U_{y\min} \langle \;\; U_{yi} \langle \;\; U_{YMAX}\, y_{\max}, \qquad \text{then}$$

$$U_{yi} = U_{yi} + \Delta I \; .K_{I0}$$

If

$$U_{ym} \;\rangle\; y_{\max}, \quad \text{then} \quad U_{ym} = y_{\max}$$

If

$$U_{ym} \;\langle\; y_{\min}, \quad \text{then} \quad U_{ym} = y_{mix}$$

Where

ΔI –Deviation of the actual current from reference sub phase.

Δt – Step work system control.

Uym– Voltage control amplitude.

Uyi– Integral component of voltage control.

Uymin– Minimum value control voltage.

Uymax– Maximum value control voltage.

KIi– Coefficient integration for the deviation current.

KIo– Coefficient of current deviation.

IZ –The arms of bridge currents.

Simulation result saw tooth voltage described Instantaneous value of voltage control VSI When sinusoidal PWM represented in equations (21,22, 23 and 24).

$$\tau = \tau + \omega * \Delta t \quad (21)$$

$$u_{y1m} = U_{ym} \sin(\tau) \quad (22)$$

$$u_{y2m} = U_{ym} \sin(\tau - \frac{2\pi}{3}) \quad (23)$$

$$u_{y3m} = U_{ym}\sin(\tau - \frac{4\pi}{3}) \quad (24)$$

Where t, time in secondω, reference value frequency angular by rad/sec, Uy max,
The amplitude maximum voltage Pu.

Sinusoidal PWM with zero sequence represented in equations (25,26 and 27).

$$u_{y1m} = U_{ym}\sin(\tau) + 0.13 * U_{ym}\sin(3\tau) \quad (25)$$

$$u_{y2m} = U_{ym}\sin(\tau - \frac{2\pi}{3}) + 0..13 * U_{ym}\sin(3\tau) \quad (26)$$

$$u_{y3m} = U_{ym}\sin(\tau - \frac{4\pi}{3}) + 0.13 * u_{ym}\sin(3\tau) \quad (27)$$

V. RESULTS OF SIMULATION

The Modeling system by interconnected sub circuit to calculate transient and steady state models of VSI. For reference load power of 100 KW and power factor 0.5 to 0.8 to hold series calculation.

Voltage phase calculation

$$v_{\phi} = \frac{\sqrt{2}}{3}U_m = 0.38 * 1000 = 380v \quad (28)$$

Load current calculation

$$I_{\phi} = \frac{P_L}{3U * \cos\phi} = \frac{30000}{380 * 0.5 * 3} = 175.438A \quad (29)$$

where P.F.0.5

$$Z = \frac{U_{\phi}}{I\phi} = \frac{380}{175.438} = 2.1660\Omega \quad (30)$$

$$R = Z\cos\phi = 2.166 * 0.5 = 1.080\Omega \quad (31)$$

$$X = Z\sin\phi = 0.0189\Omega \quad (32)$$

$$L = \frac{X}{\omega} = \frac{0.0189}{314.15} = 0.061mH \quad (33)$$

VI. MODULATION SYSTEM CONTROL AND CALCULATION TRANSIENT REGION

Input data for the program represented a table (1).The development complex of mathematical models of electrical drives with semiconductor converter and load by using C++ builder programmer. The calculations (for given load power 100KW and power factor load 0.5 to 0.8).

Table (1) Definitive input data

Emf power supply	Ei	1000 V.
The inductance of power supply	Li	0.0005 H
Active resistance of the power supply	Ri	0.01 Ω
Capacity of the capacitor	C	0.002 F
Resistance of the capacitor battery	Rc	0.01 Ω
The resistance of protective resistor	Rz	1000 Ω
Inductive load	Ln	0.022 H
Resistance load	Rn	9.24 Ω
The amplitude of emf load	Enm	0 V
The angular frequency emf load	omega	314.15 rad/s
input data for control system		
Frequency of the reference value	fop	2000 Hz
Frequency rated of load voltage	f1	50 Hz
Maximum voltage control	Uymx	1.8 Pu
Maximum voltage across the capacitor	Ucmx	1500 Vc
The specified operating load current	Inz	32.89 A
The coefficient of the integral of the current load	Kii	0.25 Pu
The coefficient of the load current	Kio	0.025 Pu

Table (2) represented where P.F. to change (0.5 to 0.8) Calculation result for I, R and L by used formula (28,29,30,31,32 and 33).

Table (2) result for I, R and L(cos φ 0.5 to 0.8)

cos φ	0.5	0.6	0.7	0.8
I_{Φ}	175.438	146.1988	125.31	109.6491
R	1.08	1.559	2.1227	3.2772
L	0.00597	0.0066	0.0068	0.0066

VII. ALGORITHM CALCULATIONS PROGRAMS

Figure 4 shows the flowchart programming for calculation and solution equation by using C++ and visual C++ [8]- [9].

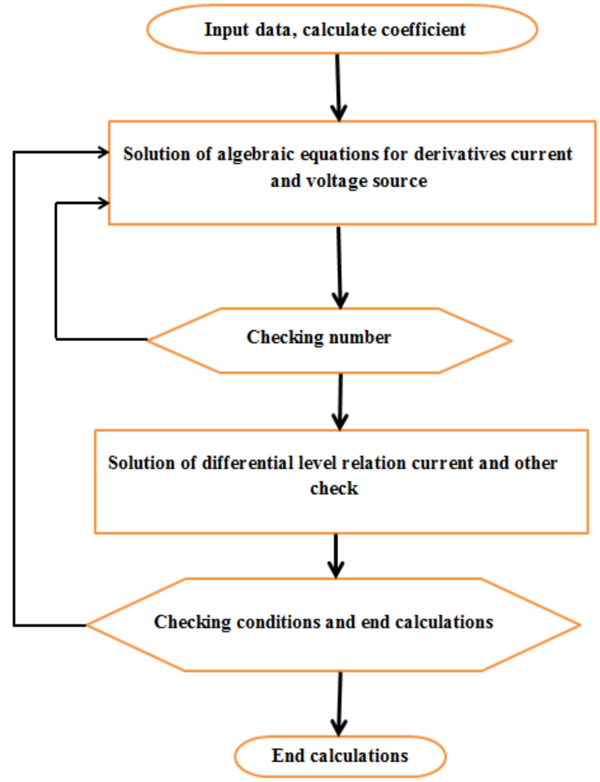

Fig. 4 Algorithm calculations programs

The results are shown in Fig.(5,6 and 7) and the table (3) when P.F.=0.5

Table (3) Harmonic analysis ($\cos \emptyset = 0.5$)

Source current: 29.918		
The rectified voltage: 999.700		
Current in the first switch		
The current value of the curve: 37.169 The maximum value of the curve: 75.266 The minimum value of the curve: -75.273		
Voltage Inverter 1 phase		
The current value of the curve: 445.914		
Harmonic freq.(Hz)	Act. Of harmonic Value	Phase (grad)
50	379.981	-94.4640
Harmonics coefficient: 0.5233		
Current 1 phase load		
The current value of the curve: 52.556		
Harmonic freq.(Hz)	Act. Of harmonic Value	Phase (grad)
50	52.550	-154.5692
Harmonics coefficient: 0.01486		
Voltage control		
Acting value of the curve: 0.797		
Harmonic freq.(Hz)	Act. Of harmonic Value	Phase (grad)
50	0.796	-94.4071
Harmonics coefficient: 0.04566		

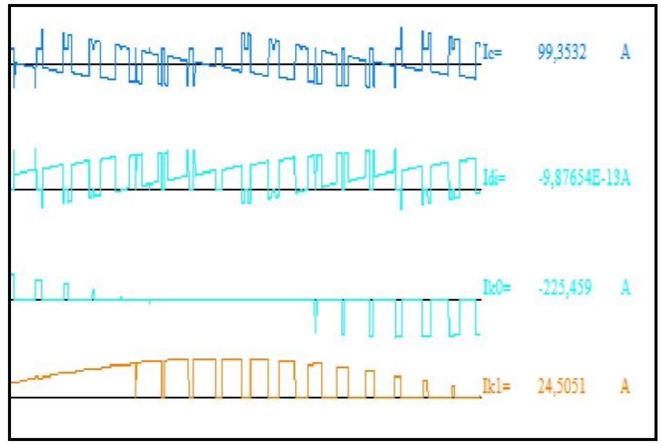

Figure 5 Schemes of characteristic current (I_c, I_{di}, I_{k0} and I_{k1})

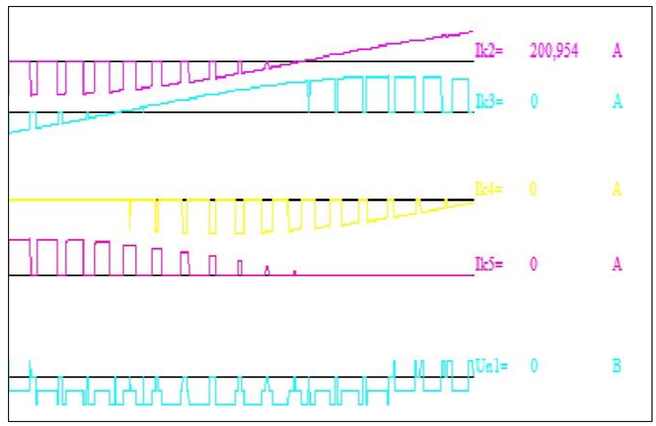

Figure 6 Characteristic current and voltage of SC (I_{k2}, I_{k3}, I_{k4}, I_{k5} and U_{n1})

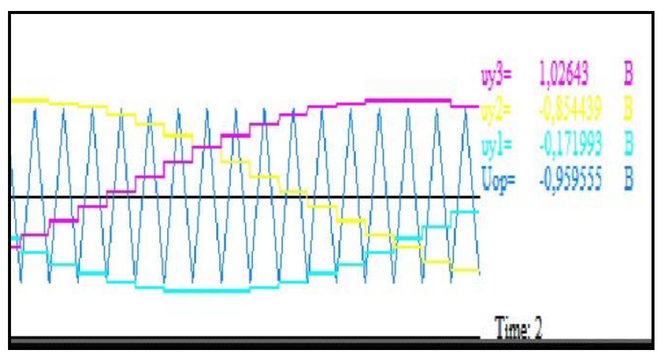

Figure 7 Characteristic of voltage PWM reference at f_1 = 2000 Hz (carrier frequency).

The results shows in Fig.(8, 9and 10) and the table (4) when P.F.= 0.6.

Table (4) Harmonic analysis ($\cos\emptyset = 0.6$)

Source current: 29.899		
The rectified voltage: 999.702		
Current in the first switch		
The current value of the curve: 30.971 The maximum value of the curve: 62.698 The minimum value of the curve: -62.643		
Voltage Inverter 1 phase		
The current value of the curve: 444.636		
Harmonic freq.(Hz)	Act. Of harmonic Value	Phase (grad)
50	378.981	-94.4701
Harmonics coefficient: 0.5248		
Current 1 phase load		
The current value of the curve: 43.781		
Harmonic freq.(Hz)	Act. Of harmonic Value	Phase (grad)
50	43.775	-147.5263
Harmonics coefficient: 0.01604		
1 control voltage		
Acting value of the curve: 0.787		
Harmonic freq.(Hz)	Act. Of harmonic Value	Phase (grad)
50	0.787	-94.4039
Harmonics coefficient: 0.04563		

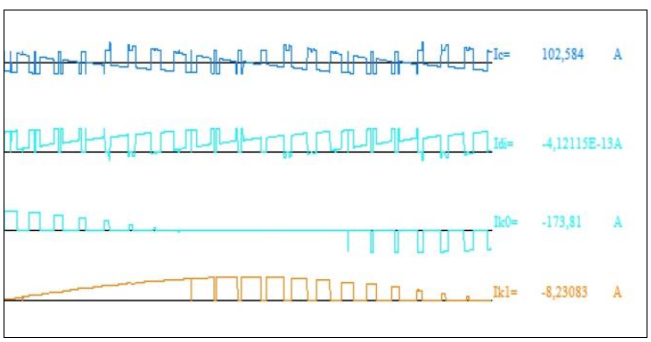

Figure 8 Schemes and characteristic current (I_c, I_{di}, I_{k0} and I_{k1})

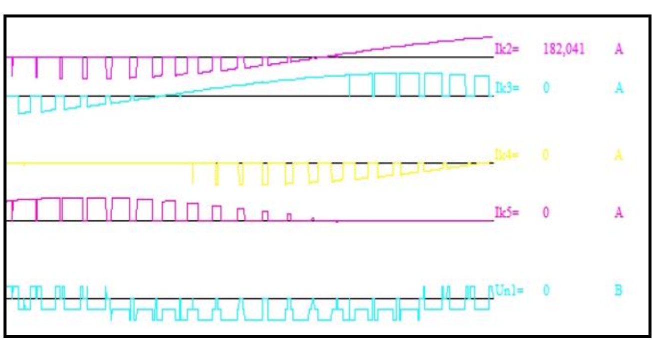

Figure 9 Characteristic current and voltage of SC (I_{k2}, I_{k3}, I_{k4}, I_{k5} and U_{n1})

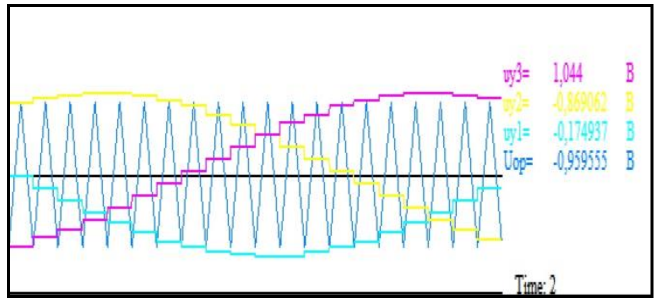

Figure10 Characteristic of voltage PWM reference at f_1 = 2000 Hz (carrier frequency)

The results are shown in Fig.(11,12 and 13) and the table (5) when P.F.= 0.7

Table (5) Harmonic analysis ($\cos\emptyset = 0.7$)

Source current: 29.864		
The rectified voltage: 999.703		
Current in the first switch		
The current value of the curve: 26.579 The maximum value of the curve: 53.810 The minimum value of the curve: -53.873		
Voltage Inverter 1 phase		
The current value of the curve: 445.192		
Harmonic freq.(Hz)	Act. Of harmonic Value	Phase (grad)
50	379.244	-94.3962
Harmonics coefficient: 0.5273		
Current 1 phase load		
The current value of the curve: 37.561		
Harmonic freq.(Hz)	Act. Of harmonic Value	Phase (grad)
50	37.561	-140.0594
Harmonics coefficient: 0.01792		
1 control voltage		
Acting value of the curve: 0.791		
Harmonic freq.(Hz)	Act. Of harmonic Value	Phase (grad)
50	0.790	-94.3779
Harmonics coefficient: 0.04567		

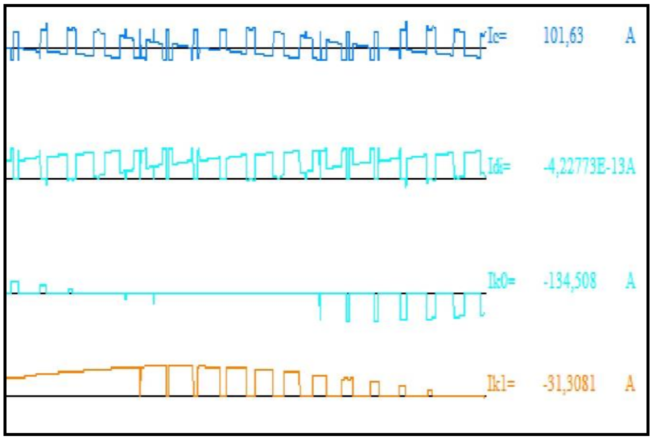

Figure 11 Schemes and characteristic current (I_c, I_{di}, I_{k0} and I_{k1})

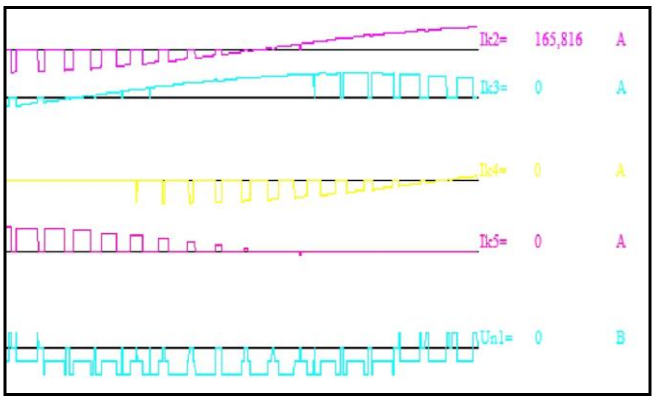

Figure 12 Characteristic current and voltage of SC (I_{k2}, I_{k3}, I_{k4}, I_{k5} and U_{n1}).

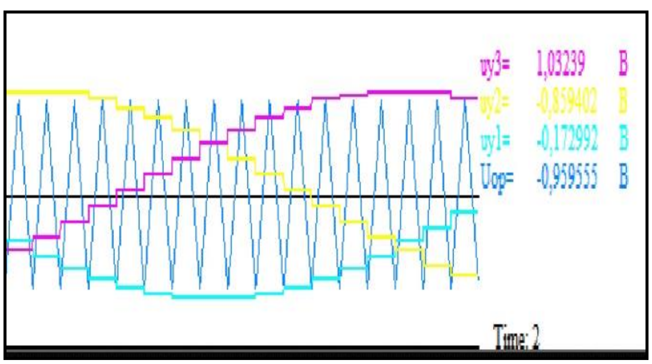

Figure 13 Characteristic of voltage PWM .

Reference at f_1 = 2000 Hz (carrier frequency The results shows in Fig.(14, 15 and 16) and the table (6) when P.F.= 0.8

Table (6) Harmonic analysis ($\cos\emptyset = 0.8$)

Source current: 29.880		
The rectified voltage: 999.701		
Current in the first switch		
The current value of the curve: 23.243 The maximum value of the curve: 47.457 The minimum value of the curve: -47.056		
Voltage Inverter 1 phase		
The current value of the curve: 444.757		
Harmonic freq.(Hz)	Act. Of harmonic Value	Phase (grad)
50	378.632	-94.4475
Harmonics coefficient: 0.5246		
Current 1 phase load		
The current value of the curve: 32.843		
Harmonic freq.(Hz)	Act. Of harmonic Value	Phase (grad)
50	32.836	-131.2152
Harmonics coefficient: 0.02118		
1 control voltage		
Acting value of the curve: 0.789		
Harmonic freq.(Hz)	Act. Of harmonic Value	Phase (grad)
50	0.788	-94.3920
Harmonics coefficient: 0.04575		

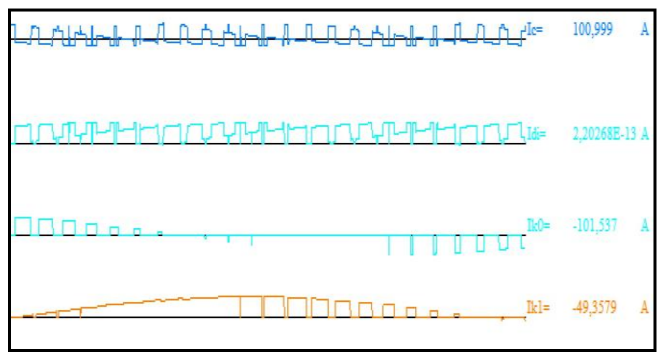

Figure 14 Schemes and characteristic current (I_c, I_{di}, I_{k0} and I_{k1}

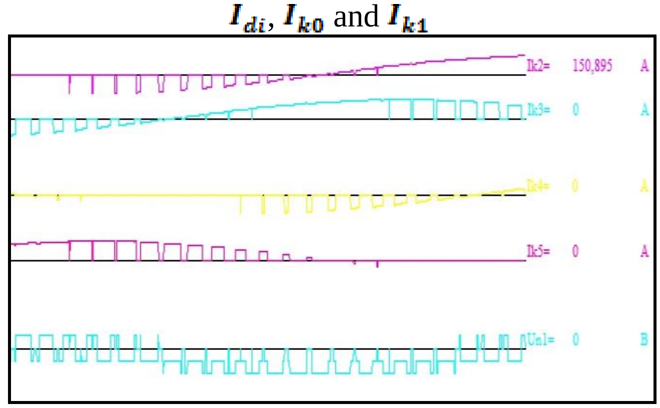

Figure 15 Characteristic current and voltage of SC (I_{k2}, I_{k3}, I_{k4}, I_{k5} and U_{n1})

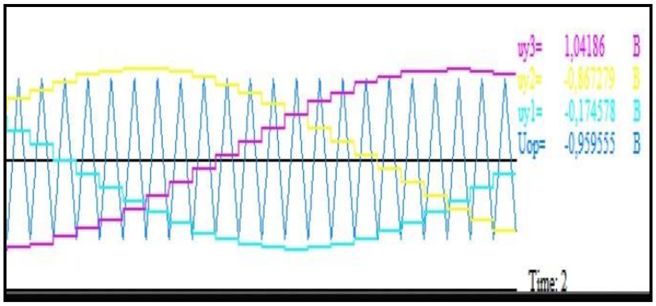

Figure16 Characteristic of voltage PWM reference at f_1 = 2000 Hz (carrier frequency).

VIII. Modulation and calculation 3Ø – 2 level INVERTOR .

Installation the small value of capacitance in part of the rectified current at a given load power of 30 KW with P.F. 0.8. Table (7) represented parameter of the load:

Table (7) given load power of 30 KW with P.F. 0.8.

Po, KW	$cos Ø$	,Volt$U_Ø$
30	0.8	$0.38 * U_п$

We calculated parameters by the following equas.

$$V\phi = \frac{\sqrt{2}}{3} U_m = 0.38 * 1000 = 380V$$

$$P_Ø = 3 * U_Ø * I_Ø * \cos Ø$$

$$I_Ø = \frac{P_L}{3U_Ø * \cos Ø} = \frac{30000}{380 * 0.8 * 3} = 32.89 \text{ A}$$

$$|Z_n| = \sqrt{R_n{}^2 + X_n{}^2}$$

$$Z_N = \sqrt{R_N + jWL_N} = \frac{U_Ø}{I_Ø} = 9.24$$

$$\cos Ø = \frac{R_N}{\sqrt{R_N + jWL_N}}$$

$$R_N = \sqrt{\frac{(Z_N)^2}{1.36}} = 9.24\ \Omega$$

$$L_N = \frac{15.212}{523.33} = 0.0022 \text{ mH.}$$

When input data for the program represented in Table (8). The development of complex mathematical models of electrical drives with semiconductor converter and load by using C++ builder programmer. The series of calculations (for given load power 30KW and power factor load 0.8, exchange capacitor.

Table (8) Definitive input data.

Emf power supply	Ei	1000 V.
The inductance of power supply	Li	0.0005 H
Active resistance of the power supply	Ri	0.01 Ω
Capacity of the capacitor	C	0.002 F
Resistance of the capacitor battery	Rc	0.01 Ω
The resistance of protective resistor	Rz	1000 Ω
Inductive load	Ln	0.022 H
Resistance load	Rn	9.24 Ω
The amplitude of emf load	Enm	0 V
The angular frequency emf load	omega	314.15 rad/s
input data for control system		
Frequency of the reference value	fop	2000 Hz
Frequency rated of load voltage, Hz	f1	50 Hz
Maximum voltage control	Uymx	1.8 Pu
Maximum voltage across the capacitor	Ucmx	1500 Vc
The specified operating load current	Inz	32.89 A
The coefficient of the integral of the current load	Kii	0.25 Pu
The coefficient of the load current	Kio	0.025 Pu

The results are shown in Fig.(17, 18 and 19) and the table (9) when C= 2 µf.

Table (9) Harmonic analysis.

current supply	30.327	
The voltage of the capacitor battery		
The average value of the curve:	999.817	
Maximum value of the curve:	1006.159	
Maximum value of the curve:	992.737	
current capacitor bank	17.56	
Un1 load voltage		
Harmonic freq.(Hz)	Act. Of harmonic Value	Phase (grad)
50	444.587	-94.4950
In1 load current		
The current value of the curve:	32.813	
Harmonic freq.(Hz)	Act. Of harmonic Value	Phase (grad)
50	32.813	-131.2492

Power Supply: P_s = 30.327*999.824 = 31268,49W

Load Power: P_L = 3*378.356*32.804*0.8 = 29787.816 W

Load Power Ref.: P_{ref} = 30000 W

$\emptyset_u - \emptyset_i$ = -94.4950 – (-131.2492) = 36,7542

Cos ($\emptyset_u - \emptyset_i$) = 0.801

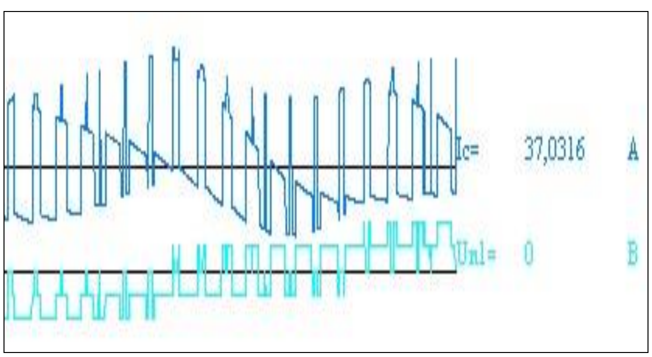

Figure 17 Capacitor current and load voltage

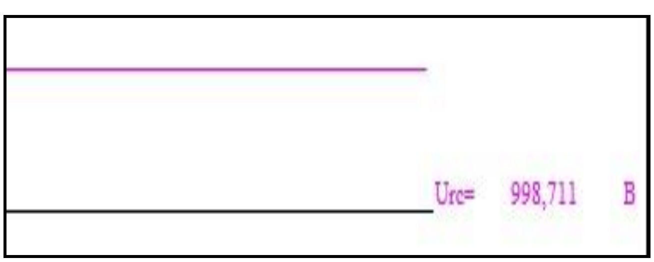

Figure 18 The rectified voltage when C=2μf

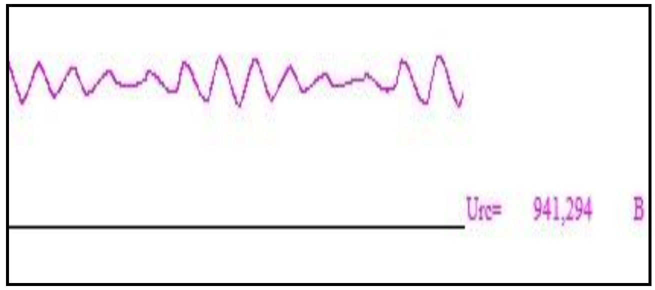

Figure 19 The rectified voltage when C=0.025 μf.

Further calculation: we used another values for capacitor changing from 2 μf to 0.035 μf .

Table 10 represented results of calculation

The capacity of the capacitor bank C,μf	Voltage of the capacitor bank (maximum value)U_{rc} ,V	Ripple of the rectified voltage$M$%	Current of capacitor bank (rms value of the curve) I_{rc}, A
2	1001.210	0,2	15.717
1	1002.110	0,4	15.763
0.1	1022.744	4,4	16.825
0.05	1057.155	11,4	18.528
0.025	1092.040	18,4	20.567
0.035	1157.938	23,14	25.257

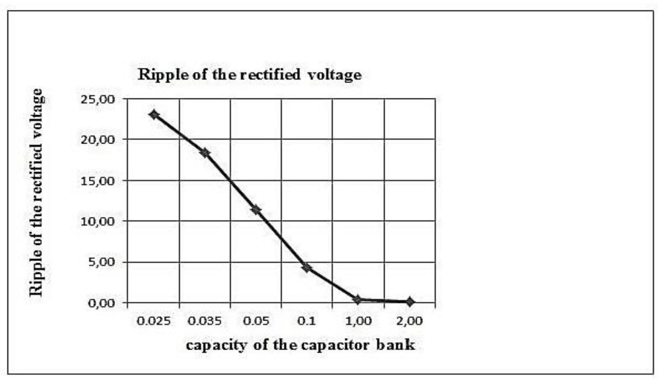

Fig. 20. Represented the relation between ripple of the rectified voltage and capacity of the capacitor bank

IX. Conclusion

In this paper, the Mathematical Driving Model of Three Phase, Two Level Inverter designs is done. The degree of linear load is described. Power factor is the proportion of power at the first harmonic of the current of the total power consumed by the load. For each nonlinear distortion have P.F and are introduced. In this paper The fluctuations of the rectified voltage does not greater than +/- 10% with installation of capacitor bank C > 0.030 Micro F. It is shown that an approach of taking into account influence of current distribution in the rotor on starting characteristics used in building up the model proved applicable for evaluation of HF energy losses caused by PWM SC. This Mathematical model of electric drives done with synchronous machines has been developed. It can use in the real time mode with the help of personal computers. The system is intended for debugging transistor drive microprocessor-based control units and based on use of mathematical models.

REFERENCES

[1] M. Pronin, "Simulation and analysis of the system with multiphase induction generator and multi-stage active rectifier", Electrotechnika, Russia, p. 55-61, no. 5, 2006.

[2] M .Pronin. A. Vorontsov,"Dependence of current pulsations of multi-phase electrical machine on reduction of winding pitch and scheme of semiconductor converter". EPE-PEMC, Portoroz, Slovenia, 2006.

[3] C. Cester, A.Kedous -Lebouc, and B. Cornut, "Iron loss under practical working conditions of a PWM powered induction motor". Magnetics, IEEE Transactions, Vol. 33, Issue 5, Part 2, pp. 3766-3768, 1997.

[4] A. J.Moses, F. Anayi ,"Effect of PWM Voltage Excitation in Iron Loss of Inverter Fed Motors", IEEE Transactions on Magnetics,vol. 40 (2), no 2, pp. 762-765, 2004.

[5] A.Ruderman, R. Welch," Electrical Machine PWM Loss Evaluation Basics", EEMODS 2005, 5 – 8 Heidelberg / Germany, September 2005..

[6] N.Serov, P.Kalachikov, M. Pronin, and A.Vorontsov," Electro-transmission of dump trucks BelA Z with capacity up to 136 t // An. Mining equipment and electro mechanics", Russia, no5, p. 22-25., 2005.

[7] M. B .Пронин, "Электроприводы и системы с электрическими машинами и полупроводниковыми преобразователями (моделирование, расчет, применение)." ЕА Крутякова СПб, Силовыемашины Электросила, Russia , p 252 ,2004.

[8] Г. Корн, Т. Корн," Справочник по математике для научных работников и инженеров". М., «Наука», p 832 c, 1978.

[9] Пронин, Михаил Васильевич, and A. Г. Воронцов." Силовые полностью управляемые полупроводниковые преобразователи (моделирование и расчет). СПб, ОАО Электросила", Russia ,2003.