International Journal of Innovative Research and Advanced Studies (IJIRAS)
Volume 3 Issue 8, July 2016

ISSN: 2394-4404

Implementation Of Average Model Of Inverter Using Transient Simulation Techniques

Shilpa George

PG Scholar, Dept of EEE, Mar Baselios College of Engineering and Technology, Trivandrum

Prof. A. S. Shajilal

Professor, Dept of EEE, Mar Baselios College of Engineering and Technology, Trivandrum

Abstract: Inverter are widely used for power electronic applications for the purpose of converting DC voltage to AC. This paper presents the implementation of average model of three phase inverter using Forward Euler method. Generalised state space averaging method is used to model the inverter. The transient analysis of inverter is done in C environment. The simulation is done and the output voltage and current waveforms are obtained.

Keywords: Transient simulation, Average model, Forward Euler, Backward Euler, Trapezoidal method.

I. INTRODUCTION

Within the last decade, there have been rapid changes in technology. Power electronics have played a vital role in the technological developments. Inverters are extensively used in power electronic applications for converting DC (Direct Current) to AC (Alternating current). The applications of inverters range from uninterrupted power supplies used in home appliances control to HVDC power transmission. Inverter circuits are quite complex and modelling of inverters have been studied extensively by researchers.

In [1], the authors present a generalized state space averaging model of inverter, by taking dead time into consideration. The proposed model guarantees accuracy in fundamental components of voltage and current. The model proves to work well in controller design of parallel connection of inverters. An average inverter model working in two complementary modes like the current controlled mode and the voltage controlled modes is discussed in [2].The proposed model takes into consideration the the nonlinear behavior of the switches, delays in the control loops, and the practical constraints. The authors were able to simulate active and reactive power controls of the inverter in two different ways and also to estimate the low order harmonics of the output current, using the proposed model.

Most of the existing inverter models are valid for a specific topology under study and models adopt a balance assumption among input variables, which limit their application ranges. A new-formed model which is a general one and more suitable for computer simulation is presented in [3]. The proposed model makes no extra assumptions and the equation are formed using KVL (kirchhoff voltage law) and KCL (kirchhoff current law).The model is a general one and can be applied to type of source/load voltages.

A functional simulation model for the voltage-source inverter (VSI) using the switching function concept is proposed and implemented in [4]. With the functional model, the simplification of the static power circuits can be achieved and also need for forming the state equations describing the power circuits in MATLAB is not required.

This paper presents the implantation of an average model of the three phase inverter using transient simulation methods. Section II gives the average model of the three phase inverter. Section III gives the transient simulation implementation of the inverter average model. Section IV gives the simulation and results.

II. AVERAGE MODEL OF INVERTER

A three phase 3- wire inverter is shown in Fig 1. A series inductance L and the equivalent series resistor (ESR) rL are placed in each of the three phases. A capacitor, C is placed across the two branches. The load is assumed to be symmetrical R load in delta connection.

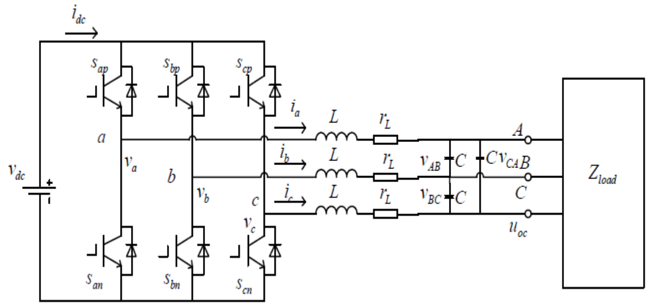

Figure 1: Three phase 3-wire inverter

The modelling of inverter is done using Generalised state space averaging method [1]. The voltages at the points a, b, c are given by equations (1) through (3).

$$v_{ab} = v_a - v_b = L\frac{d(i_a - i_b)}{dt} + r_L(i_a - i_b) + V_{AB} \quad (1)$$

$$v_{bc} = v_b - v_c = L\frac{d(i_b - i_c)}{dt} + r_L(i_b - i_c) + V_{BC} \quad (2)$$

$$v_{ca} = v_c - v_a = L\frac{d(i_c - i_a)}{dt} + r_L(i_c - i_a) + V_{CA} \quad (3)$$

The virtual currents line currents i_{ab}, i_{bc}, i_{ca} are given by equations (4) through (6).

$$i_{ab} = C\frac{dV_{AB}}{dt} + \frac{1}{R}V_{AB} \quad (4)$$

$$i_{bc} = C\frac{dV_{BC}}{dt} + \frac{1}{R}V_{BC} \quad (5)$$

$$i_{ca} = C\frac{dV_{CA}}{dt} + \frac{1}{R}V_{CA} \quad (6)$$

The virtual currents line currents i_{ab}, i_{bc}, i_{ca} are related to to i_a, i_b, i_c by the equations (7) through (9).

$$i_a = i_{ab} - i_{ca} \quad (7)$$

$$i_b = i_{bc} - i_{ab} \quad (8)$$

$$i_c = i_{ca} - i_{bc} \quad (9)$$

The voltages are related to input dc voltage and switching functions by the following equations (10) through (12).

$$v_{ab} = v_a - v_b = (s_a - s_b).V_{dc} \quad (10)$$

$$v_{bc} = v_b - v_c = (s_b - s_c).V_{dc} \quad (11)$$

$$v_{ca} = v_c - v_a = (s_c - s_a).V_{dc} \quad (12)$$

The conventional state equations for the three phase inverter are given by equations (13) through (18).

$$\frac{di_{ab}}{dt} = -\frac{r_L}{L}i_{ab} - \frac{1}{3L}V_{AB} + \frac{1}{3L}v_{ab} \quad (13)$$

$$\frac{di_{bc}}{dt} = -\frac{r_L}{L}i_{bc} - \frac{1}{3L}V_{BC} + \frac{1}{3L}v_{bc} \quad (14)$$

$$\frac{di_{ca}}{dt} = -\frac{r_L}{L}i_{ca} - \frac{1}{3L}V_{CA} + \frac{1}{3L}v_{ca} \quad (15)$$

$$\frac{dV_{AB}}{dt} = -\frac{1}{RC}V_{AB} + \frac{1}{C}i_{ab} \quad (16)$$

$$\frac{dV_{BC}}{dt} = -\frac{1}{RC}V_{BC} + \frac{1}{C}i_{bc} \quad (17)$$

$$\frac{dV_{CA}}{dt} = -\frac{1}{RC}V_{CA} + \frac{1}{C}i_{ca} \quad (18)$$

The switching function is given by equation (19).

$$s_k = \frac{m}{2}\cos(\omega t - \emptyset_k) + \frac{1}{2} \quad (19)$$

where k = a, b, c and m is the modulation ratio taken as 0.5. $\emptyset_a = \emptyset_0$, $\emptyset_b = \emptyset_0 + \frac{2\pi}{3}$, $\emptyset_c = \emptyset_0 - \frac{2\pi}{3}$ where $\emptyset_0$ is the initial phase angle.

III. IMPLEMENTATION USING TRANSIENT SIMULATION TECHNIQUE

For the study of dynamic performance of the inverter, various transient simulation methods are studied. For transient analysis, the differential equations are converted into difference equation using a suitable mathematical method. The three mathematical methods include Forward Euler, Backward Euler and Trapezoidal Methods. The three methods are analysed on the basis of accuracy, stability and computational effort by taking a simple example given by equation (20).

$$\frac{dx}{dt} = -x \quad (20)$$

While considering equation (20) with an initial condition of x (0) = 1 we get the exact solution as $x(t) = e^{-t}$[5].

While applying the three methods to the example given by equation 20 we get the results as given by equation(21) through (23)

$$\text{FE: } \frac{x_{n+1} - x_n}{h} = -x_n \quad (21)$$

$$\text{BE: } \frac{x_{n+1} - x_n}{h} = -x_{n+1} \quad (22)$$

$$\text{TRZ: } \frac{x_{n+1} - x_n}{h} = -\frac{1}{2}(x_n + x_{n+1}) \quad (23)$$

where h is the step size used in the simulation.

Analysing these three methods on the basis of accuracy, it is found that in FE and BE methods error α h2 and in TRZ method error α h3. In terms of stability, BE and TRZ methods give comparable results and FE method gives unstable results when h is greater than the time constant of the circuit. In case of BE and TRZ methods to find the values at n+1 we need to know x_{n+1} values also but in case of FE method, the values at n+1 can be found out with the help of nth values.

The transient analysis of inverter is done using FE method while carefully choosing the step size, h without affecting the stability of the circuit. The differential voltage and current equations can be converted to difference equation using FE method. The corresponding ac voltage and ac current thus obtained are given by equations (24) through (29).

$$i_{ab}^{n+1} = h * \left[-\frac{r_L}{L}i_{ab} - \frac{1}{3L}V_{AB} + \frac{1}{3L}(s_a - s_b).V_{dc}\right] + i_{ab} \quad (24)$$

$$i_{bc}^{n+1} = h * \left[-\frac{r_L}{L}i_{bc} - \frac{1}{3L}V_{BC} + \frac{1}{3L}(s_b - s_c).V_{dc}\right] + i_{bc} \quad (25)$$

$$i_{ca}^{n+1} = h * \left[-\frac{r_L}{L}i_{ca} - \frac{1}{3L}V_{CA} + \frac{1}{3L}(s_c - s_a).V_{dc}\right] + i_{ca} \quad (26)$$

$$V_{AB}^{n+1} = \frac{h}{C}i_{ab} + V_{AB} \quad (27)$$

$$V_{BC}^{n+1} = \frac{h}{C} i_{bc} + V_{BC} \quad (28)$$

$$V_{CA}^{n+1} = \frac{h}{C} i_{ca} + V_{CA} \quad (29)$$

IV. SIMULATION AND RESULTS

The simulation of the three phase inverter using Forward Euler technique is done in C environment. The simulation is done for 1s and the step size was taken as 100 µs. A dc input voltage of 100 V is given to the inverter and the output voltage and current waveforms are obtained. The parameters used for simulation is given in Table 1.

SYMBOL	PARAMETERS	VALUE	UNIT
Vdc	Input Voltage	100	V
m	Modulation Ratio	0.6	-
f	Fundamental frequency	50	Hz
φ0	Initial phase angle	0	rad/s
L	Filtering Inductor	1.0	mH
rL	ESR of filtering inductor	1.245	Ω
C	Filter Capacitor	1.0	mF
R	Load Resistance	10	Ω

Table 1: Simulation Parameters

The input to the three phase inverter is a dc input voltage of 100 V as given in Fig 2.

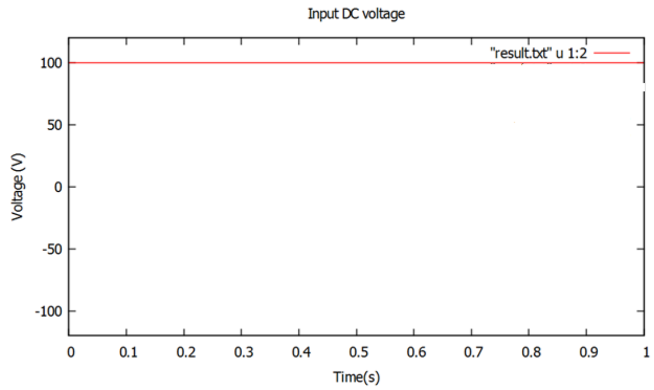

Figure 2: Dc input voltage of 100V

(Scale: x-axis 1div= 0.1s y-axis 1div=50V)

The output phase voltages obtained for the three phase inverter is shown in Fig 3.

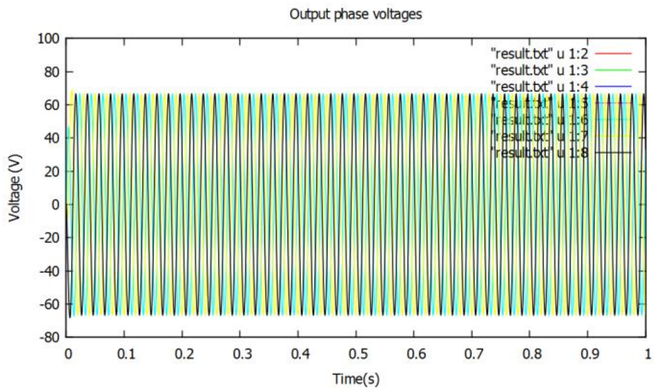

Figure 3: Three phase output voltages of inverter

(Scale: x-axis 1div= 0.1s y-axis 1div=20V)

The output phase currents obtained for the three phase inverter is given in Fig 4.

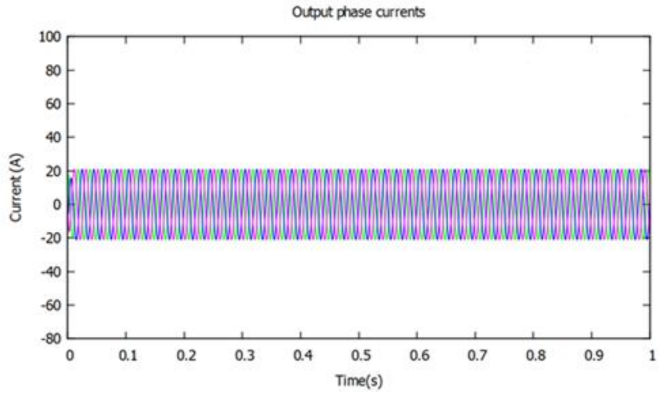

Figure 4: Three phase output currents of inverter

(Scale: x-axis 1div= 0.1s y-axis 1div=20A)

V. CONCLUSION

In this paper, the generalized state space average model of the inverter is implanted using transient simulation techniques. For transient simulation analysis, various mathematical techniques are studied. The comparison of the three mathematical methods like Forward Euler, Backward Euler and trapezoidal methods is done on the basis of Accuracy Stability and computational Effort required. The waveforms of output voltage and output currents are obtained.

REFERENCES

[1] Zhao Lin and Hao Ma. (2013). Modeling and Analysis of Three-phase Inverter based on Generalized State Space Averaging Method, IEEE Annual Conference on Industrial Electronic Society, 1007-1012. doi: 10.1109/IECON.2013.6699271.

[2] Zeljko Jankovic, Bora Novakovic, Vijay Bhavaraju and Adel Nasiri. (2014). Average modeling of a three-phase inverter for integration in a microgrid, IEEE Energy Conversion Congress and Exposition (ECCE), 793–799. doi: 10.1109/ECCE.2014.6953477

[3] Runxin Wang, Jinjun Liu. (2009). Redefining a New-Formed Average Model for Three-Phase Boost Rectifiers/Voltage Source Inverters, The 24th Applied Power Electronics Conference and Exposition, 1680-1686. doi: 10.1109/APEC.2009.4802895

[4] Byoung-Kuk Lee, Mehrdad Ehsani. (2001). A Simplified Functional Simulation Model for Three-Phase Voltage-Source Inverter Using Switching Function Concept, IEEE Transactions on Industrial Electronics, 48, 309-321. doi: 10.1109/41.915410.

[5] M. B. Patil, V. Ramanarayanan, V. T. Ranganathan. (2013). Simulation of Power Electronic Circuits, Narosa Publishing House Pvt. Ltd.

[6] Dr. P. S. Bimbhra. (2009). Power Electronics, Khanna Publishers, Fourth Edition.