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Comparative Study of Average Model of Diode Rectifier with the Model Developed by Modified Nodal Analysis Method

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Abstract:

This paper presents two methods for modeling three phase diode rectifier. The average model of the three phase diode rectifier is compared with the rectifier model developed by Modified Nodal Analysis method. The simulation is done in C environment and the waveforms of output voltage for both the methods are obtained. The average model gives appreciable results with simple equations, but modeling the rectifier using modified nodal analysis method is quite time consuming and a tedious task. The paper discusses the advantages of using average model over the other model.

Keywords: Three phase diode rectifier, Modified nodal analysis method and Average method

1. Introduction

The need for various converters in the industrial world is increasing day by day. The role of diode rectifiers is significant in the power electronics applications. The applications of rectifiers include supply of polarized voltage for welding, power supplies for the electronic instruments like television, computer etc.

The concept of average model of rectifiers was studied and developed before by engineers and researchers. In [1] the author presents a new model of rectifier that is more suitable for computer simulations. This model does not use any assumptions for the source or load that can be used for the rectifier circuit. So it gives the freedom to use any type of load and source balanced / unbalanced, symmetrical / asymmetrical, sinusoidal / non- sinusoidal. The paper gives a clear idea of how to deal with branches purely consisting of inductors and voltage loops purely consisting of capacitors. The model simply uses KCL and KVL to get the current and voltage values and does not make any extra assumptions. This model uses inductor currents as state variables and the model is a general model unlike the other existing models.

A new average value model to simulate a controlled rectifier is presented in [2]. The operation of controlled rectifier in both continuous and discontinuous modes is studied. The response of the circuit in both transient and steady state conditions are analyzed. The generalized state space averaging approach along with the duty ratio constraint is used to model the diode rectifier.

This paper presents a comparative study between the average model of the rectifier and the model developed by Modified Nodal Analysis method. Section II represents the rectifier model by Modified Nodal Analysis method. Section III represents the average model rectifier in continuous conduction. Section IV shows the simulation results for the two models.

2. Modified Nodal Analysis Method

Consider the diode rectifier shown in Figure 1.

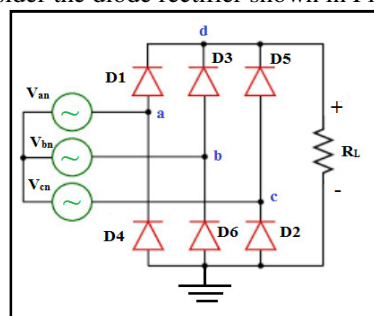


Figure 1: A three phase diode rectifier

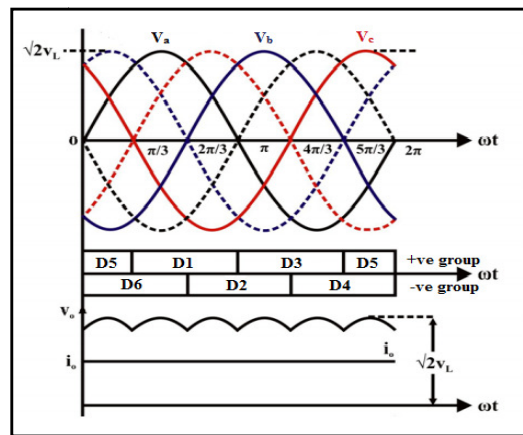


Figure 2: Sample input voltage, timing diagram and sample output voltage and current waveforms

The three phase input voltages and the timing diagram of the diodes and the output voltage and the output current are given in Figure 2. The value of the load resistor is taken as 10 k Ω . In Modified Nodal Analysis method, the circuit for the diodes of the rectifier is replaced by an off resistance of 1 M Ω and an on resistance of 1 m Ω . The simplified circuit diagram for the diode rectifier hence obtained by replacing the diodes with their resistance values for an interval when diodes D5 and D6 conducts is shown in Fig 3.

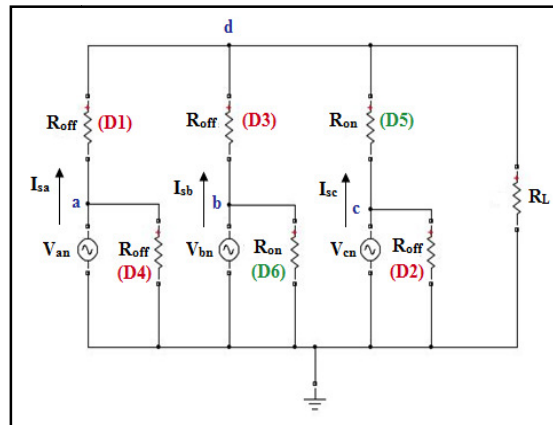


Figure 3: Simplified circuit diagram of rectifier when both D5 and D6 conducts

The nodal equations at the nodes a, b, c and d are given by equations (1) through (4).

$$\frac{V_a}{R_{off}} + \frac{V_a - V_d}{R_{off}} + I_{sa} = 0 \quad (1)$$

$$\frac{V_b}{R_{on}} + \frac{V_b - V_d}{R_{off}} + I_{sb} = 0 \quad (2)$$

$$\frac{V_c}{R_{off}} + \frac{V_c - V_d}{R_{on}} + I_{sc} = 0 \quad (3)$$

$$\frac{V_d - V_a}{R_{off}} + \frac{V_d - V_b}{R_{off}} + \frac{V_d - V_c}{R_{on}} + \frac{V_d}{R_L} = 0 \quad (4)$$

The nodal equations are written in the matrix form to get the equation $AX = Z$, where X is the unknown matrix containing the nodal voltages, Z is the input matrix and the A represents the circuit impedance.

$$\begin{bmatrix}
 \frac{1}{R_{off}} + \frac{1}{R_{off}} & 0 & 0 & -\frac{1}{R_{off}} & 1 & 0 & 0 \\
 0 & \frac{1}{R_{on}} + \frac{1}{R_{off}} & 0 & -\frac{1}{R_{off}} & 0 & 1 & 0 \\
 0 & 0 & \frac{1}{R_{on}} + \frac{1}{R_{off}} & -\frac{1}{R_{on}} & 0 & 0 & 1 \\
 -\frac{1}{R_{off}} & -\frac{1}{R_{off}} & -\frac{1}{R_{on}} & \frac{1}{R_{on}} + \frac{2}{R_{off}} + \frac{1}{R_L} & 0 & 0 & 0 \\
 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
 0 & 0 & 1 & 0 & 0 & 0 & 0
 \end{bmatrix}
 \begin{bmatrix}
 V_a \\
 V_b \\
 V_c \\
 V_d \\
 I_{sa} \\
 I_{sb} \\
 I_{sc}
 \end{bmatrix}
 =
 \begin{bmatrix}
 0 \\
 0 \\
 0 \\
 0 \\
 V_{an} \\
 V_{bn} \\
 V_{cn}
 \end{bmatrix}$$

To find out the nodal voltages, A inverse matrix is multiplied with the input matrix, Z. The A inverse matrix for the various conduction intervals are shown below.

For $\omega t = 0$ to 30° and $\omega t = 330$ to 360° ,

$$A^{-1} = \begin{bmatrix}
 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
 0 & 0 & 0 & 0.000999 & 9.99 \times 10^{-10} & 9.99 \times 10^{-10} & 0.999 \\
 1 & 0 & 0 & 9.99 \times 10^{-10} & -0.00000199 & 9.99 \times 10^{-16} & 9.99 \times 10^{-7} \\
 0 & 1 & 0 & 9.99 \times 10^{-10} & 9.99 \times 10^{-16} & -1000.000001 & 9.99 \times 10^{-7} \\
 0 & 0 & 1 & 0.999 & 9.99 \times 10^{-7} & 9.99 \times 10^{-7} & -0.000102
 \end{bmatrix}$$

For $\omega t = 30$ to 90° ,

$$A^{-1} = \begin{bmatrix}
 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
 0 & 0 & 0 & 0.000999 & 0.999 & 9.99 \times 10^{-10} & 9.99 \times 10^{-10} \\
 1 & 0 & 0 & 0.999 & -0.000102 & 9.99 \times 10^{-7} & 9.99 \times 10^{-7} \\
 0 & 1 & 0 & 9.99 \times 10^{-10} & 9.99 \times 10^{-7} & -1000.000001 & 9.99 \times 10^{-16} \\
 0 & 0 & 1 & 9.99 \times 10^{-10} & 9.99 \times 10^{-7} & 9.99 \times 10^{-16} & -0.00000199
 \end{bmatrix}$$

Similarly, other matrices are found out for conduction time period of $\omega t = 90$ to 150° , $\omega t = 150$ to 210° , $\omega t = 210$ to 270° and $\omega t = 270$ to 330° . The rectifier model is simulated using C code and the A inverse matrix is chosen according to the on state of the 6 diodes.

3. Average Model of Diode Rectifier

The average model is obtained by a generalized state- space average method that can be used for both continuous and discontinuous modes of operation [2]. This method is applied to a six-pulse rectifier model as shown in Figure 4.

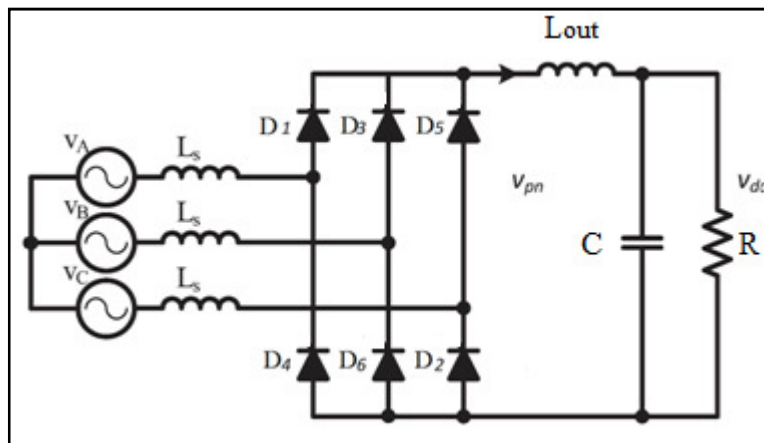


Figure 4: A three phase diode rectifier with R load and an output filter

The circuit consist of three ac input sources, input inductances, L_s in each phase, the switches S_1 through S_6 , output inductor L_{out} , filter capacitor, C and Resistor, R form the load of the rectifier circuit.

The switching functions for the three phases are repented by the following equation (5).

$$s_{abc} = \frac{2\sqrt{3}}{\pi} (\sin(\omega t) \quad \sin\left(\omega t - \frac{2\pi}{3}\right) \quad \sin\left(\omega t - \frac{4\pi}{3}\right)) \quad (5)$$

The input currents at the three phases are given by equation (6).

$$i_{abc} = s_{abc} i_{dc} \quad (6)$$

The average dc output voltage of the converter is given by equation (7).

$$v_{pn} = s_{abc}^T v_{abc} = L_{out} \frac{di_{dc}}{dt} + v_{dc} \quad (7)$$

The dc link current is given by the equation (8).

$$i_{dc} = C \frac{dv_{dc}}{dt} + \frac{v_{dc}}{R} \quad (8)$$

4. Simulation and Results

The modelling of the three phase diode rectifier using the above two methods and it is simulated in C environment. The results are analyzed and presented below. It is found that the average model is applicable for any type of source and load. But by using modified nodal analysis method if change the load the number of nodes may change and solving the equations and finding the new matrix becomes really difficult.

The input voltage for the three phases given to the three phase diode rectifier is shown in Figure 5. The output voltage of three phase diode rectifier modelled using modified nodal analysis method is given in Fig.6. It is obtained for a resistive load of $10k\Omega$. To get pure dc voltage and current, we use a filter having non-linear elements like the inductor and capacitor. These elements must be converted to linear form by replacing them with a resistor and current source. Then the number of nodes will increase and the new matrix to be solved will be of higher order.

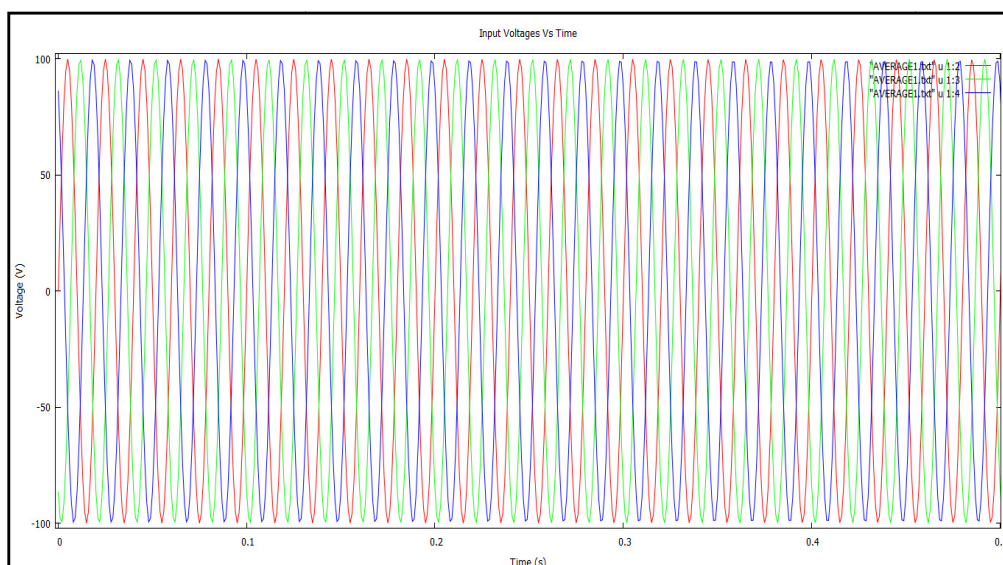


Figure 5: Three phase input voltage to the rectifier

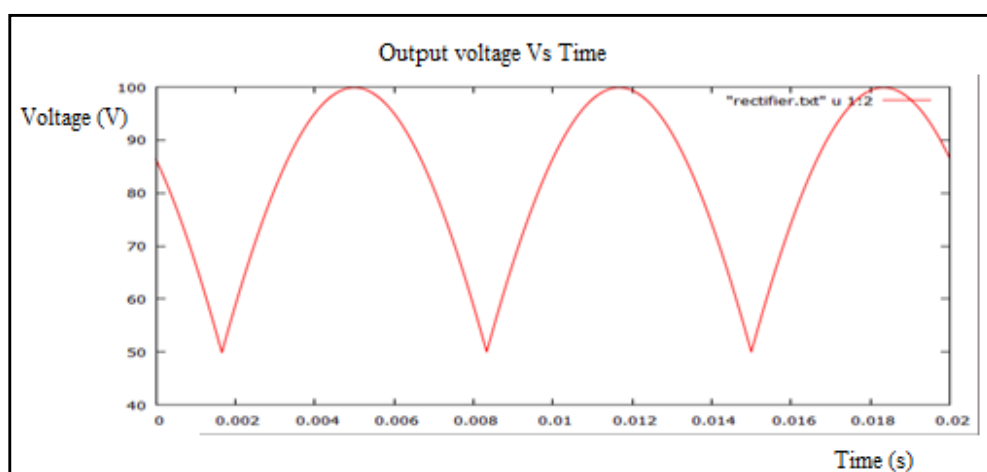


Figure 6: Output voltage of rectifier when modeled with modified nodal analysis method

The output voltage of the three phase diode rectifier (average model) is shown in Fig 7. the rectifier is modeled with a resistive load of $2\text{k}\Omega$. To get pure dc voltage and pure dc current at the output we use a filter with an inductor of 1mH and a capacitor of 1mF .

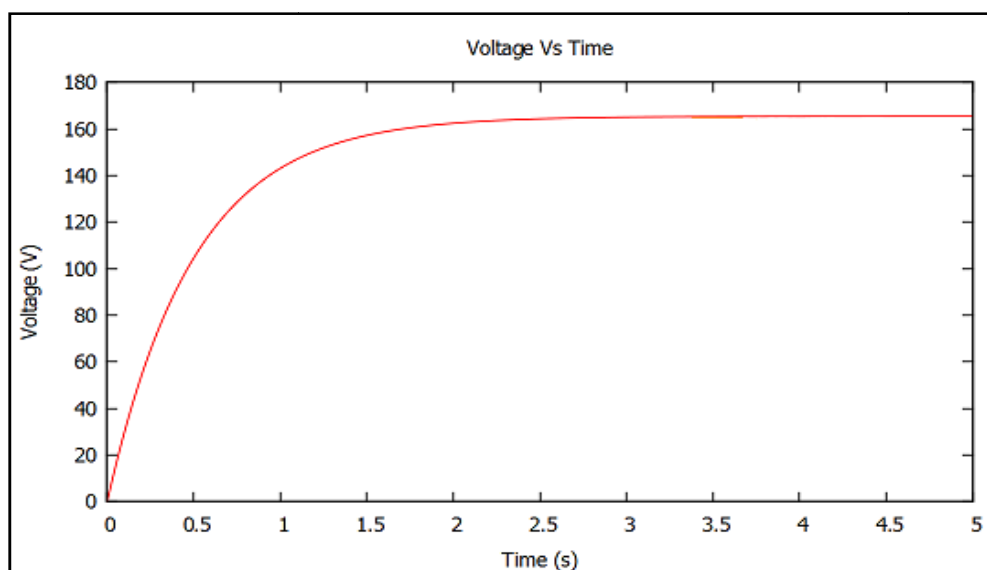


Figure 7: Output voltage for average model rectifier

5. Conclusion

The average model of three phase diode rectifier gives dc voltage and current at its output. The average modeling is simple and less time consuming. But modeling the same using modified nodal analysis method is a tedious process and its simulation uses more memory space for the storage of matrices. Also modeling of the three phase diode rectifier using modified nodal analysis method presents difficulty in case if the load contains non linear elements like inductor and capacitors. If we replace the source and load with other elements, then the new set of matrices need to be solved and even the order of the matrices can change. Hence it can be concluded that the average model of rectifier is better compared to the model developed by modified nodal analysis method.

6. References

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