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Simulink Model for Piece Wise Linear Approximation of Memristor

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Abstract: Memristor is a passive circuit element which firstly presented to science world by Leon Chua in 1971. Chua showed a missing link among four fundamental circuit variables which generate basic passive circuit elements. Chua described this missing link between charge and flux, named it as memristor. Memristor is firstly realized by Stanley Williams and his team from HP (Hewlett Packard) research laboratories in 2006. In this study, doped and undoped TiO_2 are sandwiched between two Pt layers in nano scale. And this element demonstrated voltage-current characteristic like memristor. Physically implementation of memristor is announced with a paper to science world in 2008. The studies about memristor have quite increased along with this study. In this paper, a new PWL (Piece Wise Linear) memristor model is obtained thereby linearizing current-voltage characteristic of memristor. The equivalent circuit is derived from this model, built in Simulink and results are observed. The results are compared with other studies in literature and obtained results have been shared.

Keywords: *Control Equations, Equivalent Circuit, Memristor, PWL Model, Simulink Model*

1. Introduction

Memristor is a semiconductor passive circuit element which is firstly proposed to science world by nonlinear circuit theorist Leon Chua in 1971 [1]. Fundamental passive circuit elements defined by four fundamental circuit variables: voltage, current, charge and flux. For instance; resistor is derived from relationship between voltage and current, capacitor is derived from relationship between voltage and charge and inductor is derived from relationship between current and flux. Chua noticed that there is a missing link between charge and flux. And defined this missing link as "$M = \frac{d\varphi}{dq}$" and named it "memristor". Passive circuit elements and definitions of these elements from fundamental circuit variables are shown in Fig.1.

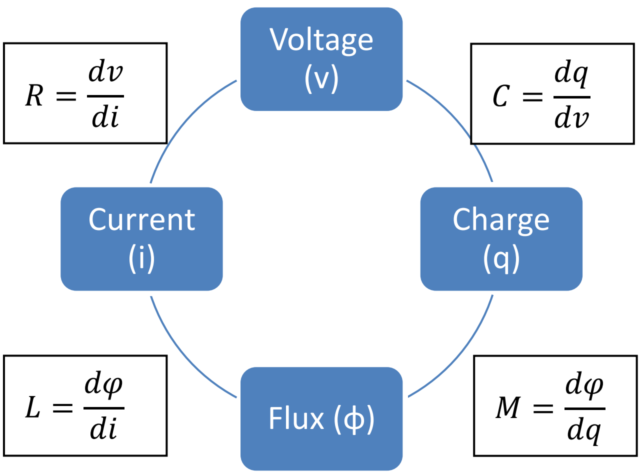

Fig 1. Passive circuit elements and relationship between circuit variables

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As the name memristor consists of a combination of the words memory and resistor. Theoretically, this element will protect last electrical quantities such as voltage or current even if energy cuts off on it. Therefore, memristor shows memory characteristic. The memristor also has resistor characteristic due to its definition equation which shown in (1). When this equation derived from type of voltage and current, equation (2) is obtained. This equation is a kind of charge dependent resistor like Ohm's Law. Memristor characterized by "memristance" whose formula is shown (1) and has electrical unit "ohm".

$$M(q) = \frac{d\varphi}{dq} \quad (1)$$

$$M\big(q(t)\big) = \frac{V(t)}{I(t)} \quad (2)$$

Voltage-current (V-I) characteristic of memristor has a hysteresis curve. I-V characteristic of memristor is shown in Fig.2. According to this characteristic, memristance value changes between two resistance values. These are represented as the highest and the lowest resistance values which have big difference values between each other. Memristance changes between these values based on applied voltage over memristor.
Memristor is also a frequency dependent circuit element which was mentioned before in Chua's paper [2]. In that paper, Chua gave frequency dependent I-V characteristic of memristor which is shown in Fig.3. According to this figure; when applied frequency is increased, hysteresis curve of I-V characteristic becomes narrow. On the other hand; when applied frequency is decreased, hysteresis curve of I-V characteristic becomes wide. When frequency goes to infinity, I-V characteristic becomes linear. Thus, memristor shows a resistor characteristic and memristance is equal to only one resistance value.

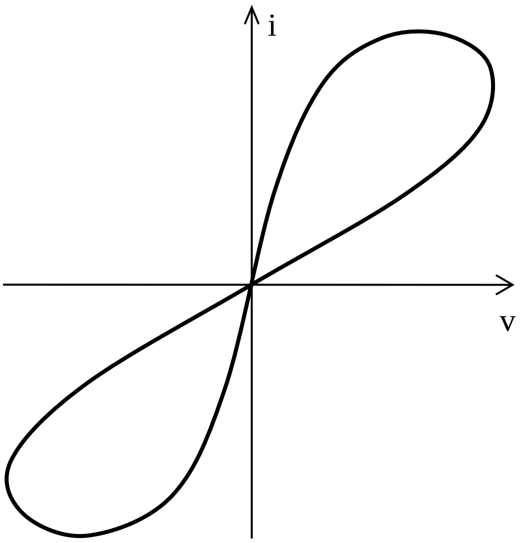

Fig 2. I-V characteristic of memristor

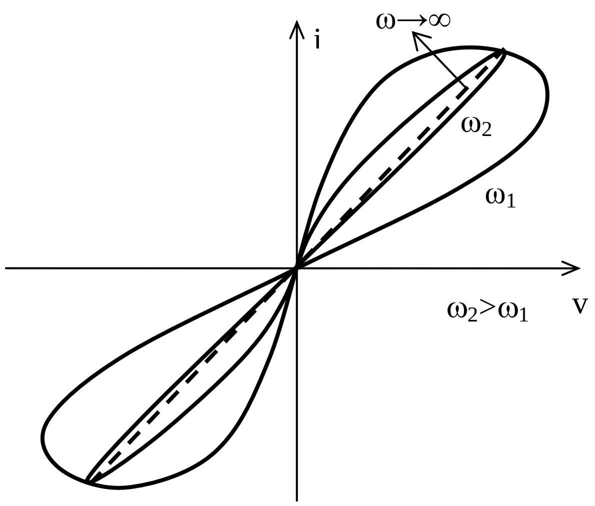

Fig 3. Frequency response of memristor's I-V characteristic [2]

In 2008, 37 years after the definition of memristor, Stanley Williams and his team from HP (Hewlett-Packard) announced that the memristor is physically implemented [3]. The team used TiO_2 which is a semiconductor material in this study. Pure TiO_2 has high resistance and doped TiO_2 with oxygen vacancies has lower resistance. These two kinds of TiO_2 sandwiched between two Pt layers and so element is obtained. Fig.4 shows HP memristor model. In this model, there is a thin film between pure and doped sides. Position of this film changes depending on energy flows from where. When energy flows from doped side to pure side, memristance value decreases. Otherwise, when energy flows from pure side to doped side, memristance value increases. These changes consist of depending on ion mobility. So, HP memristor model also called as linear ion drift model.

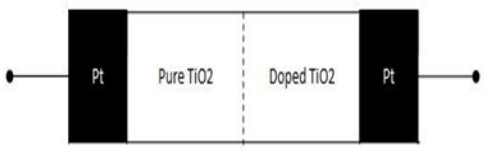

Fig 4. HP Memristor Model

After physically implementation of memristor, interest in memristor is increased dramatically. Studies about memristor have been accelerated by modelling memristor and using these models in various circuits [4]- [12]. Modelling of the memristor could also be a milestone for applications that cannot be done before because of the lack of available circuit elements and for new circuit applications which previously unthinkable but could be considered with existence of memristor.

In this paper, PWL (Piece Wise Linear) memristor model design, which is one of the memristor model, will be made using the model in Simulink. I-V characteristic and M-V characteristic of proposed memristor model will be shared. And also these results will be compared with other studies which described in literature. Suggestions and new future studies about memristor and proposed model will be written in conclusion part. Methodology section, results and comparisons section, conclusion section will be presented respectively.

2. Methodology

2.1. Piece Wise Linear (PWL) Memristor Model

Linear ion drift model [3], nonlinear ion drift model [4], [5] and Simmons tunnel barrier model [4], [5] are memristor models which are in nano size. PWL model is a different form of these models. This model is a different memristor model which depends on I-V characteristic of memristor [12]. The goal of this model is linearization of I-V characteristic of memristor. Thus, it can be obtained new equivalent circuit models and so these memristor models can be using with circuit models in memristor based circuit applications and other future circuit applications. PWL memristor model is shown in Fig.5.

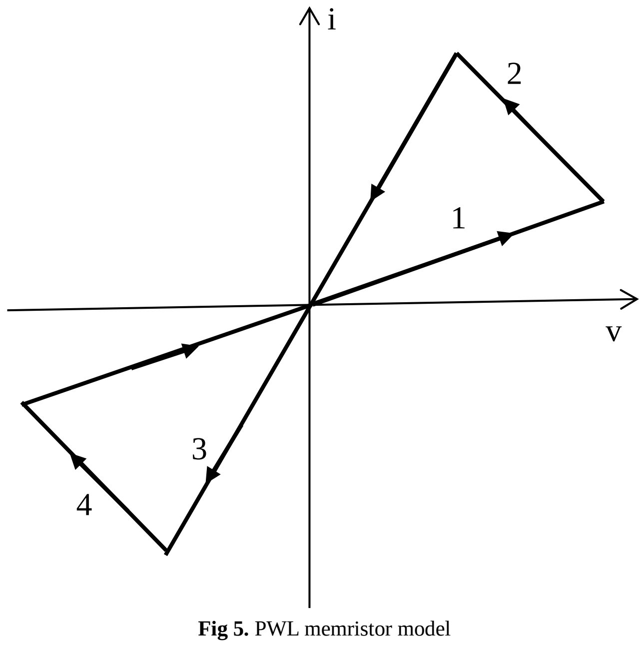

Fig 5. PWL memristor model

2.2. Proposed PWL Memristor Model

In this paper, a different PWL memristor model is proposed. Proposed PWL memristor model in simulink is shown in Fig.6.

Current-voltage characteristic and memristor-voltage characteristic of this model are shared in results and comparisons section. These characteristics are also compared with other publications in the literature. Advantages and disadvantages of the models are given and reason for the differences are explained in other sections.

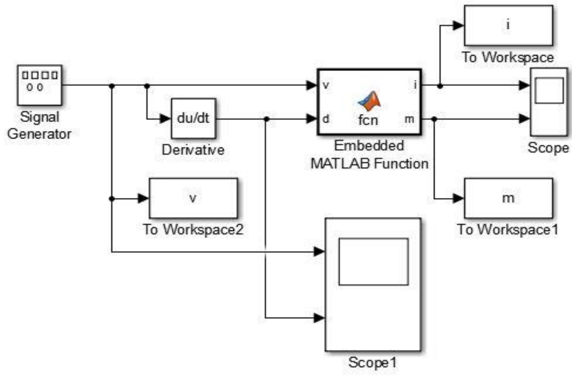

Fig 6. Proposed memristor model in simulink

In Fig.6, memristor model consists of signal generator block, derivative block, embedded matlab function block, to workspace blocks and scopes. Generator block generates sinus signal which has v(t)=3.999×sin(2πt) value. Derivative of signal is taken by derivative block. Commands that consist of control equations for operating model are written in embedded matlab function block. The operation of this block as follows: Generated signal and derivative signal which is generated by derivative block are input parameters of embedded matlab function. Processed signals in this block are obtained as output current and memristance. These current and memristance values are transferred to workspace by “to workspace” block. In workspace, current-voltage and memristance-voltage characteristics are achieved by “plot” command. Also time dependent changes of voltage, derivative of voltage, current and memristance values have been observed by scopes. Fig.7 shows voltage and derivative of voltage graphics. Top graph is voltage versus time, bottom graphic is derivative of voltage versus time. Fig.8 shows current and memristance graphics. Top graph is current versus time; bottom graph is memristance versus time.

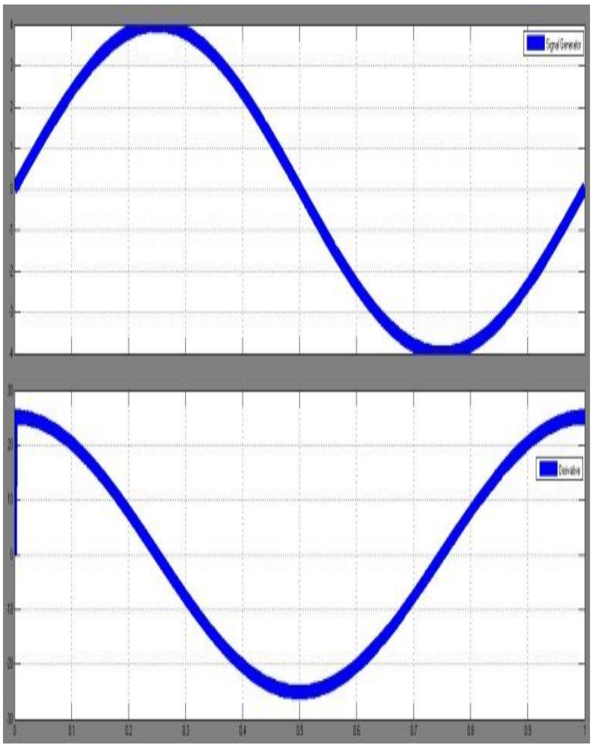

Fig 7. v and *dv/dt* graphics versus t

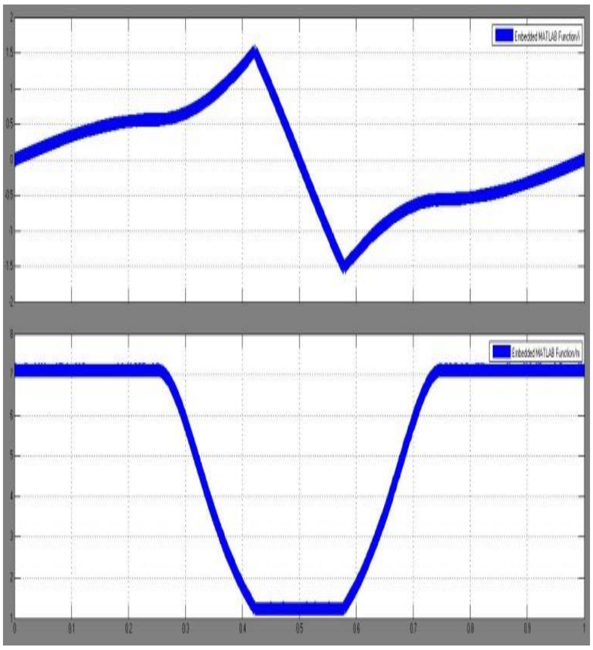

Fig 8. v and *dv/dt* graphics versus t

3. Results and Comparisons

In this section, results of proposed model and comparison of this model with other publications will be given.

Current-voltage characteristic and memristance-voltage characteristic of proposed memristor model is shown in Fig.9 and Fig.10 respectively.

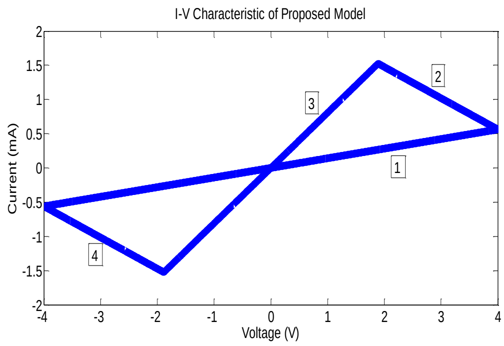

Fig 9. I-V characteristic of proposed model

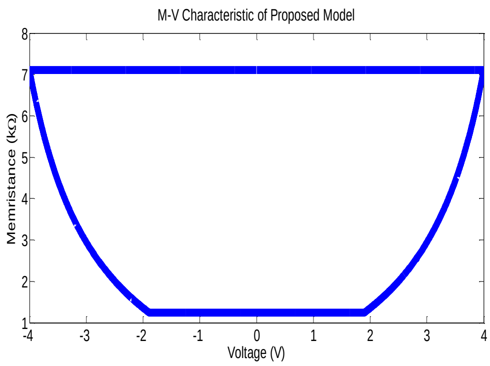

Fig 10 M-V characteristic of proposed model

I-V characteristic of proposed memristor model is obtained according to control equations. Written control equations for processing of model are as follows:

$$Region = \begin{cases} 1.region\ for\ -V_2 \le v \le V_2\ \ and\ \ \frac{dv}{dt} > 0 \\ 2.region\ for\ V_1\ \le v \le V_2\ \ and\ \ \frac{dv}{dt} < 0 \\ 3.region\ for\ -V_1\ \le v \le V_1\ \ and\ \ \frac{dv}{dt} < 0 \\ 4.region\ for\ -V_2\ \le v \le -V_1\ and\ \frac{dv}{dt} < 0 \end{cases}$$

I-V and M-V characteristics of proposed model are compared with other publications [13], [14]. Vourkas& Sirakoulis and Joglekar& Wolf models are based on HP memristor model. Proposed model is based on PWL memristor model so there is a difference between these characteristic because of that. Proposed model has linear characteristics but other models have nonlinear characteristics. The outlines of characteristics are same without this difference. Comparison of I-V and M-V characteristics are shown in Fig.11 and Fig.12 respectively. In Fig.11; red line represents Vourkas& Sirakoulis model, green line represents Joglekar& Wolf model and cyan line represents proposed model. In Fig.12; green line represents Vourkas& Sirakoulis model, red line represents Joglekar& Wolf model and cyan line represents proposed model.

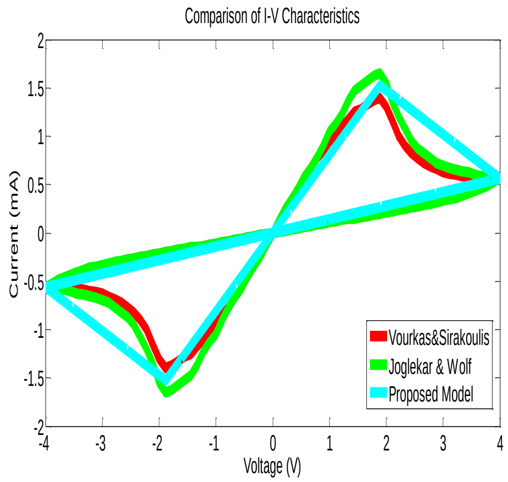

Fig 11. Comparison of I-V characteristics

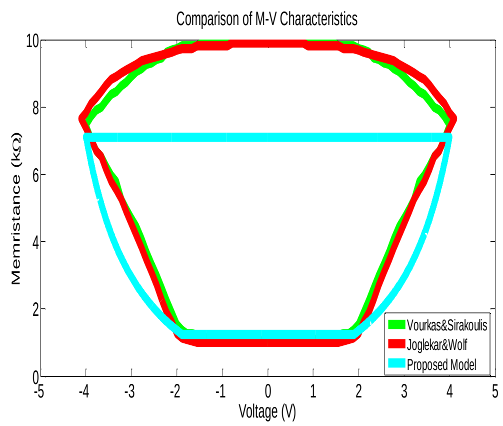

Fig 12. Comparison of I-V characteristics

This study is also an improved version of our previous study [15]. The results of previous study and these results are compatible. Also the results of this study are more compatible to Vourkas& Sirakoulis and Joglekar& Wolf models. Previous study had a gap between first and last values of both characteristics but in this study the gap is vanished. And so this model provides more suitable results.

4. Conclusion

In this paper, a new PWL memristor model is proposed. I-V and M-V characteristic of this model are obtained and compared with other publications [13]- [15]. The results of proposed model are better than results of [15]. This model will be used different circuit applications for future studies.

Acknowledgements

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