Performance of Memristor based Industrial Controllers

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Abstract— The fourth fundamental hidden passive circuit element which was offered in 1971 by Prof. Leon. O. chua is called Memristor (concatenation of memory resistor). There are three fundamental passive elements in circuits, named as; Resistor, Inductor and Capacitor; all these three elements are bilateral elements, means when direction of energy supply changes across it, the resistance offered by these three elements does not changes. In other hand Memristor does not offered bilateral behavior, when the direction of energy supply changes then the value of resistance also changes, when current is stopped; Memristor retains the last resistance that it had. It behaves like a non-linear resistor. In future, we can use Memristor as a usual flash memories. In this paper we analysed the performance of PID controller with & without Memristor on MATLAB. This paper will talk about the basic properties, fundamental device model and significant application areas of Memristor and improvement performance in PID controller using Memristor.

Key words: Memristor, V-I Characteristics, IC, Nonvolatile Memory, EM Theory, MATLAB

I. Introduction

For nearly 170 years, circuit theory is deliberate with three fundamental passive circuit elements, the resistor, the inductor and the capacitor in 1827, 1831 and 1845 respectively. These elements illustrate the relations among flux, current, charge and voltage without memory. On this conditions, in 1971 Prof. Leon .O. Chua offered a innovatory concept of the existence of the fourth hidden element called “Memristor” (concatenation of memory resistors) that can store information without the need of energy supply. In future, we can use Memristor as a usual flash memories. This paper offered a logical proportion reasons for the existence of the fourth absent element which exhibited a correlation between electric charge (q) and flux (φ). This element was named as Memristor (concatenation of Memory Resistor). It is basically a charge reliant resistor which remembers the charge that has flowed through it or the voltage that was previous applied across it.This paper basically shows that how memristor work as an advancement of PID controller.

A. *Fundamental Circuit Laws*

Resistance relates voltage and current (dv=R.di), inductance relates flux and current (d =L.di), and capacitance relates charge and voltage (dq=C.dv), respectively. As shown in Fig. 1, Chua argued that there is a missing link between flux and charge (dϕ =M.dq), which was called memristance M. Memristor acts like simply resistor if ϕ-q relationship is linear. However, if ϕ-q relationship is nonlinear and the element is charge controlled then it is considered as memristance

$$M(q) = \frac{d(\phi)}{d(q)} \qquad (1)$$

If the element is flux controlled then it is considered as memconductance.

$$Gm(\phi) = \frac{d(q)}{d(\phi)} \qquad (2)$$

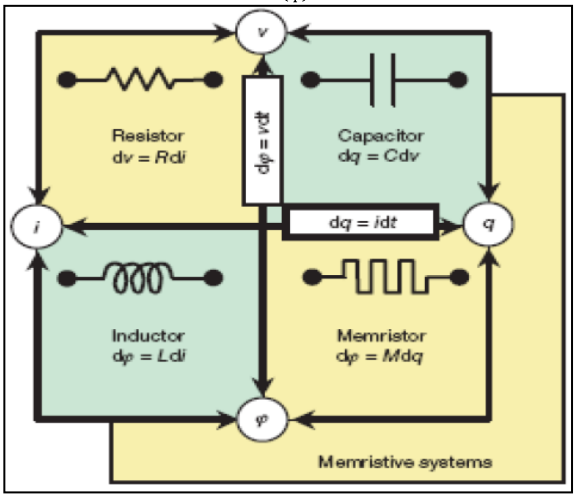


Fig. 1: Fundamental Circuit Element Relations

As defined Equation (1) can be written as follows

$$d\phi = Mdq \qquad (3)$$

By integrating (3) we got magnetic flux of the apparatus (φ) is a function of the electric charge which has passed through the apparatus.

$$\phi = f_M(q) \qquad (4)$$

Now differentiated eq.(4) with respect to time we got,

$$\frac{d\phi}{dt} = \frac{dfm(q)}{dq}\frac{dq}{dt} \qquad (5)$$

According to relation of voltage and current eq. (5) is written as follows:

$$v(t) = \frac{dfm(q)}{dq}\, i(t) \qquad (6)$$

In simple way we can write eq. (6) as follow:

$$v(t) = M(q)i(t) \qquad (7)$$

If we consider these devices have a memory of the charge that has passed through it, instead of charge, a state variable w represents the current memory state of the device.

$$v(t) = M(w)i(t) \qquad (8)$$

Thus we can say that Chua’s new circuit element have electrical resistance dependent on amount of charge flows through its terminals. Furthermore, device exhibit memory about its resistance which was in last active state, even though it not in use. Thus, we can say that Chua’s new element memristor is combination memory and resistor.

B. *Basic Memristor Models*

The basic equivalent circuit and physical structure of memresistor shown in fig.2. The device consists of electrically switchable thin semiconductor film placed between two metal contacts. Thin semiconductor film are divided into two parts named doped and undoped region of total length D. The internal state variable w represents length of doped region. normally doped region provides low resistance path while undoped region is much higher resistance path. When an external power is applied across memristor, length w will be changing because of the charged dopant drifting.

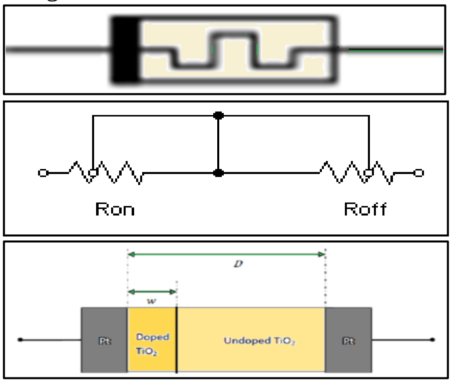


Fig. 2: Circuit Symbol & Device Structure of Memristor

R_{ON} value is measured when w increases till D (doped region extends to the full length D),that is w/D=1 Likewise, R_{OFF} value is measured when (D-w) increases till D(un-doped region extends to the full length D),that is w/D=0. Mathematically device resistance can be described as

$$R(w)=(Ron\frac{W(t)}{D}+Roff\left(1-\frac{w(t)}{D}\right)) \qquad (9)$$

Effective width of doped region at rate defined by equation

$$w(t) \;=\; \mu\frac{Von}{D} \qquad (10)$$

Where μ is average ion mobility.In terms of current i(t)the eq.(10) can be written as

$$\frac{dw(t)}{dt}=\mu\frac{Ron}{D}i(t) \qquad (11)$$

Now integrate eq.(11) with respect to time, we get

$$w(t)=\mu\frac{Ron}{D}q(t) \qquad (12)$$

Assuming Roff >> Ron and putting equation (12) into (9),& comparing with equation (7) we got

$$M(q)= \quad Roff\left(1-\mu\frac{Ron}{D2}q(t)\right) \qquad (13)$$

It is clear from above equations,that the amplitude of memristance is basically depends on charge & it is inversely proportional to square of the total length D so we can conclude that at nanometer scale memristance effect is more effective as compared to micrometer scale.

II. PROPOSED MEMRISTOR MODEL

MATLAB model of Memristor has been simulated and desired result has been obtained for different parameters.

a) Resistance Vs applied input voltage graph.
b) Current Vs voltage graph.
c) Charge Vs flux graph.

A. Simulink Model of Memristor

Basic simulink model of Memristor is shown in Fig 3.

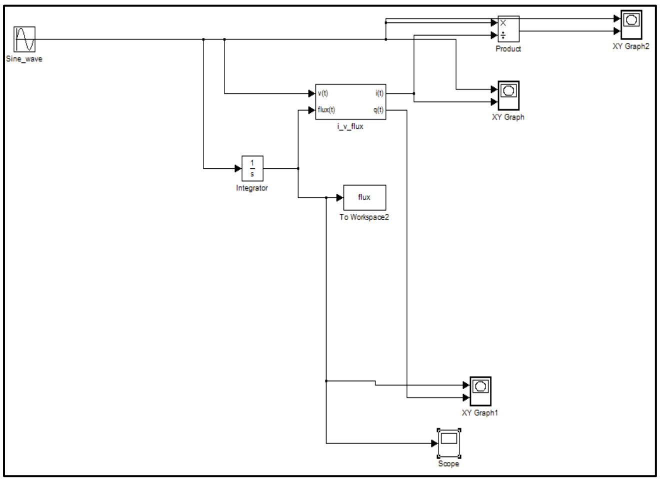


Fig 3: Simulink Model of Memristor

1) Simulink Model of Memristor Subsystem

The outlook of Memristor Subsystem is shown in Fig 4.

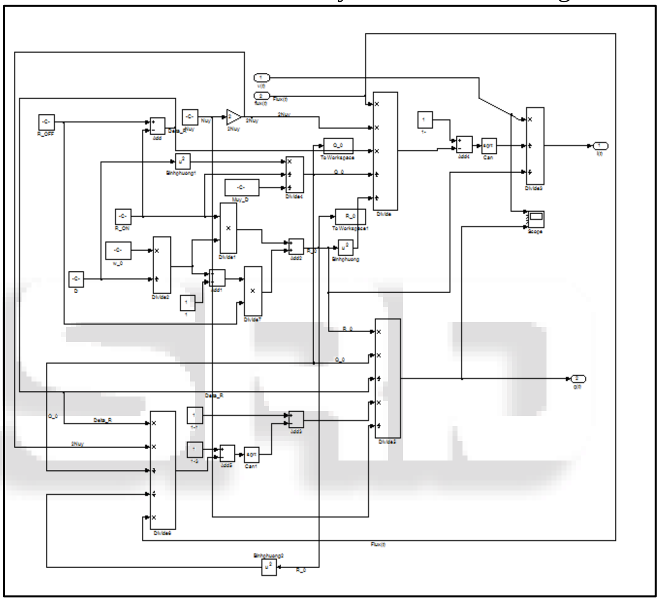


Fig 4: Simulink Model of Memristor Subsystem

B. Simulation Result of Resistance Vs Input Voltage for Memristor

We have Preveously discussed the relation between resistance and applied voltage for a memristor which are nonlinear and nonvolatile nature. Fig 5 shows the resistance Vs input voltage characteristic of memristor.

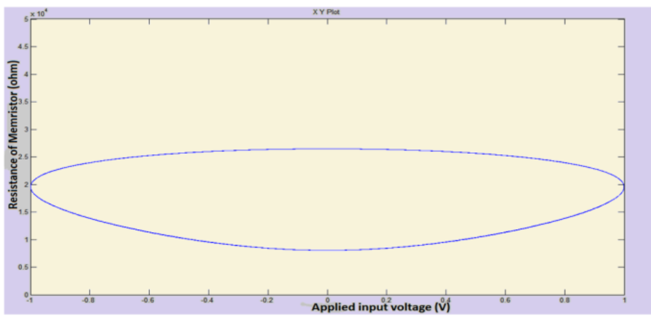


Fig. 5: Resistance Vs Input Voltage of Memristor

C. Simulation Result of Current Vs Voltage for Memristor

According to the relation which has been discussed in equation (8) as follow

$$v(t) = M(w)i(t)$$

This equation shows that if $v(t) = 0$, we get $i(t) = 0$ and $M(t)$ is constant . This is the spirit of the memory effect (nonvolatile nature). Inductor and capacitor stores energy in the form of Magnetic field $(\frac{1}{2}li2)$ & Electic field $(\frac{1}{2}cv2)$ respectively, but Memristor is not an energy storing device like L & C.

For Memristor, $v(t)= 0$ when $i(t) = 0$, so V-I curve of the device to produce a pinched hysteresis loop helpful the memory effect associated with it, which is shown in Fig 6.

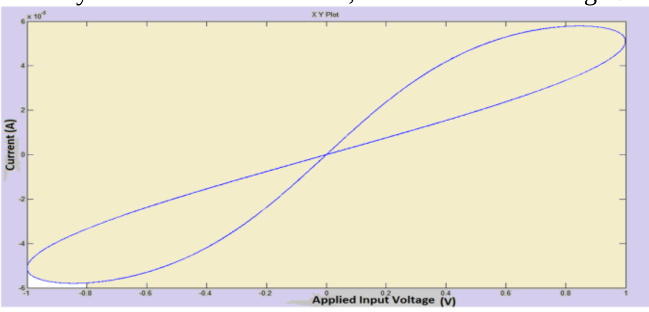


Fig. 6: V-I characteristic (Hysteresis Loop)

D. Simulation Result of Current Vs Voltage for Memristor

We have Preveously discussed in equation (1) the relation between charge (q) and flux (ϕ) for a memristor by a relation $M(q) = \frac{d(\phi)}{d(q)}$ .Fig 7 shows the charge Vs flux characteristic of Memristor.

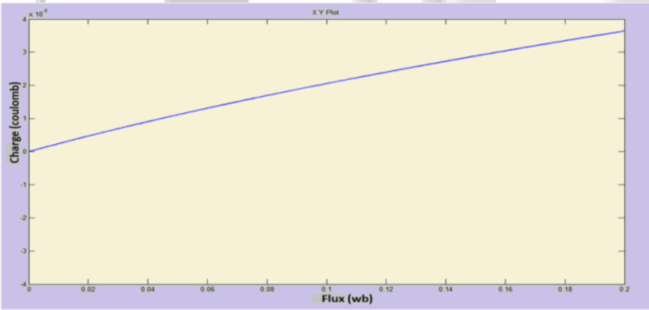


Fig. 7: charge Vs flux characteristic of Memristor

E. Flux Vs Time Waveform for Memristor the Flux Vs Time Waveform is shown in Fig 8.

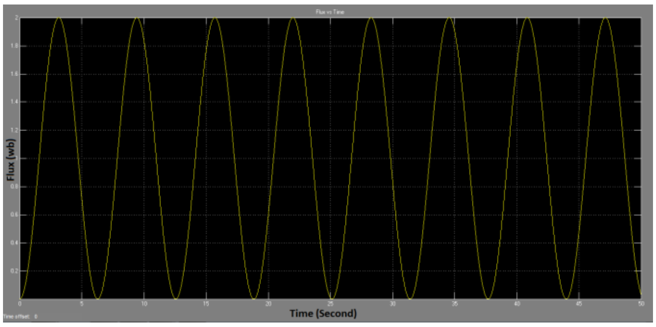


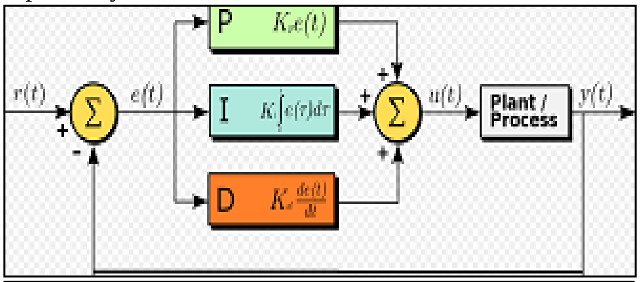
Fig. 8: Flux Vs Time Waveform

III. SIMULINK MODEL OF CLASSICAL PID CONTROLLER

PID controller is basically used for improving the transient and steady-state response of an Industrial control system equipments. PID controller operates on three action name as proportional, integral, and derivative. The overall control function can be expressed mathematically as:

$$u(t) = Kpe(t) + Ki\int_0^t e(t)dt + Kd\, de(t)/dt$$

Where Kp, Ki and Kd all non-negative, denote the coefficients for the proportional, integral, and derivative terms, respectively. The simulation model of classical PID controller & it's results are shown in Fig 9 & Fig 10 respectively.



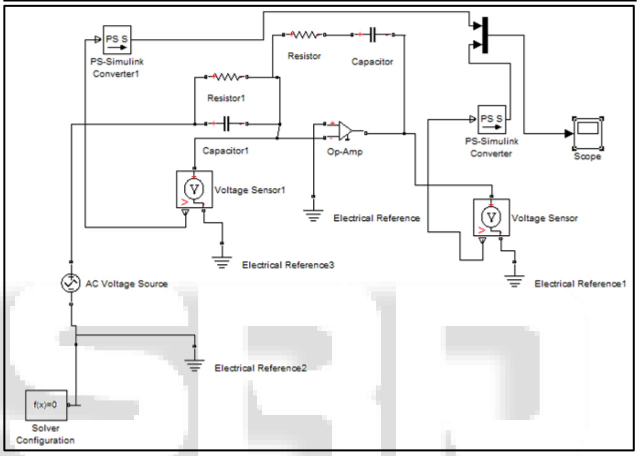


Fig. 9: Simulink Model of Classical PID Controller

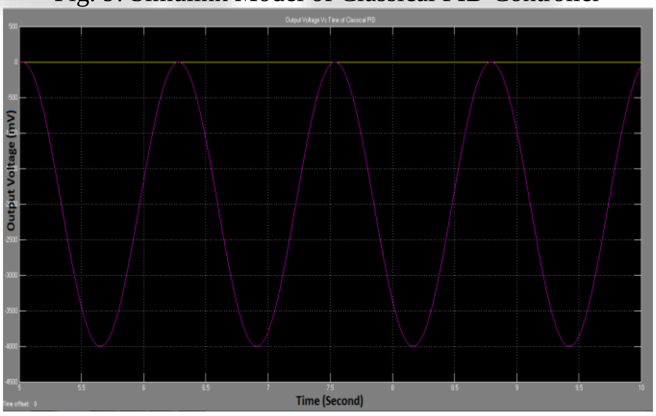


Fig. 10: Result of Classical PID Controller

IV. SIMULINK MODEL OF PID CONTROLLER USING MEMRISTOR

Memristor acts like simply resistor if ϕ-q relationship is linear. However, if ϕ-q relationship is nonlinear and the element is charge controlled then it is considered as memristance.

$M(q) = \frac{d(\phi)}{d(q)}$;If the element is flux controlled then it is considered as memconductance. $Gm(\phi) = \frac{d(q)}{d(\phi)}$ According to basic properties of three passive elements (R,L &C), Memristor have many advantages like Smaller size, Nonvolatile nature, Lower power consumption, Higher utilization, Fast & smooth control, It will operate even below the threshold voltage only require it is on,No need of rebooting time for computer, developed using memristor. Simulation model of Memristor element & its subsystem based PID controllers are shown in Fig 11. & Fig 12 respectively.

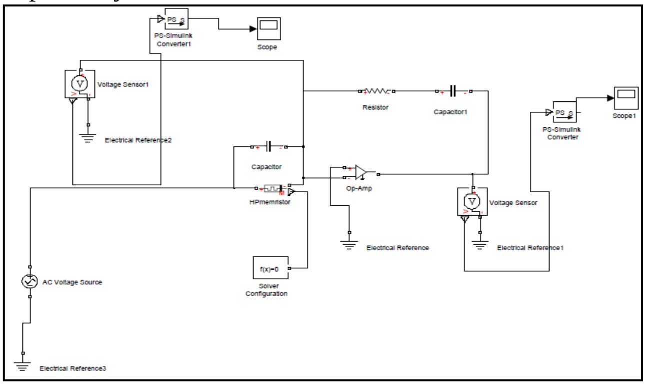


Fig 11: Simulation Model of Memristor Element Based PID Controller

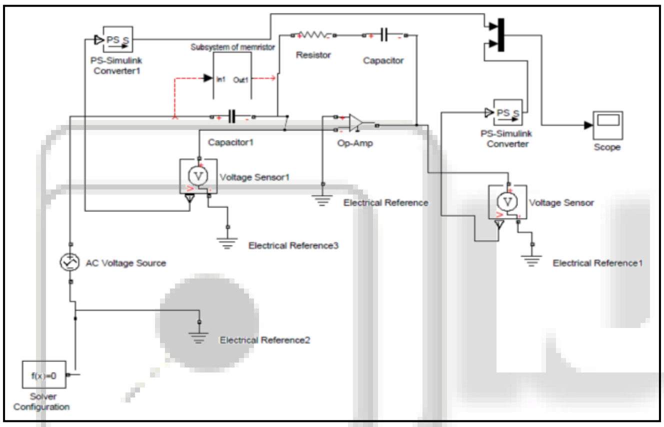


Fig 12: Simulation Model of Memristor Subsystem based PID Controller

V. FUTURE APPLICATION

Memristor based technology will be new area of research in future because it is a new passive element which do not dissipate energy so, they are good area of research for researchers. The basic areas are Digital logic implementation, Analog computation applications, Memory application, Memristor crossbar application, Neuromorphic and biological application, Crossbar latch as transistor replacement in microprocessor applications. There is also two new device such as Memcapacitor & Meminductor which show pinched hysteresis type behaviour are shown in Fig 13.

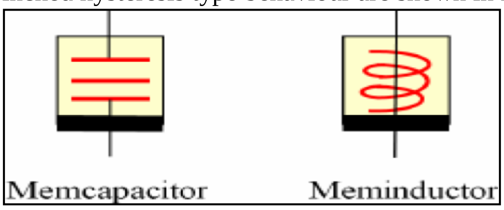


Fig. 13: Memcapacitor & Meminductor

VI. CONCLUSION

HP lab Memristor model has been discussed in detail with mathematical expression. Memristor has been simulated in MATLAB and desired results such that Resistance Vs applied input voltage characteristics, Current Vs voltage characteristics, and Charge Vs flux characteristics are obtained. Classical PID controller using op-amp has been obtained with mathematical expression & output waveform. A Memristor based PID controller is presented in MATLAB and examine its effects.

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