A study on non-linear behavior of memristor emulator using multisim

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ABSTRACT

A Memristor (memory resistor) is a two terminal non-linear passive element used to relate magnetic flux with respect to electric charge. A Memristor opposes the flow of electric current across a device like a resistor but also remember the last charge that was flowing through it. Memristor is a fourth passive circuit element after inductor 'L' resistor 'R', and capacitor 'C. The voltage and current relationship in a memristor is a multivariable function therefore analyzing the circuit is a difficult task. This paper depicts the designing of a memristor model emulator using multisim and studied about its linear and non-linear characteristics.

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1. INTRODUCTION

Memory for the resistor concept was first proposed by widrow in 1960 and named as memistor. Later in 1968, Fano et al listed an unknown passive element apart from resistor, capacitor and inductor [1]. In 1971, Prof. Leon Chua a mathematician realized the first practical and mathematical memristor. Among the four main fundamental variables current 'I' voltage 'V' charge 'q' and flux 'Ø' chua predicted that there is a missing relationship between flux and charge characterized by $g(\emptyset, q) = 0$ which has been named as a memristor [2], [3]. The missing relationship between flux and charge is shown in Figure 1. In 2008 Stanley Willams group built a nano scale chip made with TiO2 which is a nonvolatile memory resistor. A memristor emulator circuit using multisim has been proposed in this paper and studied its characteristics [1]. It is expected with a lot of potential applications on memristor [4]. Memristor can also be used as a nonvolatile memory device since it has high density and fast as DRAM [5]. Few cases has been depicted on negative shade of memristors as well [6]. It is also been used in the field of artificial neural network in the field of communication systems [7]. Itoh, M et al, presented the application of memristor as an oscillator [8] and also been used in the application of masking the signal in communication [9]. These are also used as ring oscillator physically unclonable function to improve the efficiency [10-12]. Similar devices for energy storage are emulated as well [13]. Relevant study also reviewed and implemented in application to IOT [14-16]. Other types of encryption and super capacitor devices are presented with simulation results [17], [18].

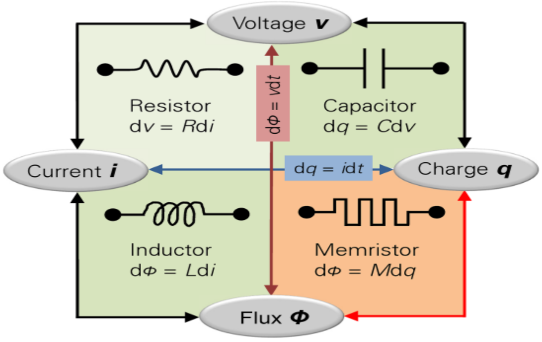

Figure 1. Missing Element Memristor

1.1. Principle

The V-I relationship in a memristor is defined as:

$$v(t) = i(t)R = \frac{d\emptyset}{dq}\, i(t) \tag{1}$$

From Equation (1) Ø(t) denotes the flux and q(t) denotes the charge with respect to the time. The resistance of the device is the gradient at the operating point in Ø-q curve. If Ø-q relationship is a nonlinear then the value of resistance varies with the operating point [19]. In the absence of external voltage the operating point will not change and the resistance remains constant. So, the signal is remembered as the value of memory resistance (Memristance'M') [3].

$$R = M = \frac{d\emptyset}{dq} \tag{2}$$

The first memristor was designed by HP Company using TiO2. The HP Company team members built a nano device and shared one common point is that it reveals pinched hysteresis loop [20]. A thin oxygen poor titanium dioxide and titanium dioxide layer are inserted between two electrodes of platinum [4].

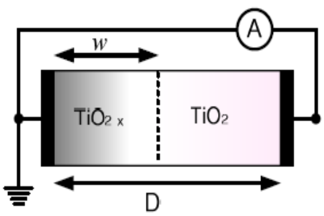

Figure 2. Physical Memristor

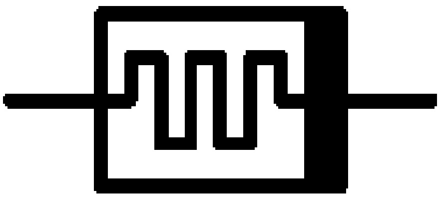

Figure 3. Memristor Symbol

Where the TiO_{2x} is an undoped layer and TiO_2 is a doped layer shown in Figure 2. When a voltage or a current is applied between the two terminals of a memristor the value of resistance will change. Here D and w denotes the thickness area and doped area . R_{ON} and R_{OFF} implies high and low level dopent concentration areas [1].

$$v(t) = \left\{Ron\ \frac{w(t)}{D}\middle|Roff\ \left(1 - \frac{w(t)}{D}\right)\right\} i(t) \tag{3}$$

The Equation three shows the relationship between voltage and current with respect to the thickness and doped area. The Symbol for a Memristor is shown in Figure 3.

Memristor can be considered as a fourth passive element with high flexibilty, no leakage current and more compatable with CMOS [21]. A Memristor is a combination of memory and a resistance which is a continuous variable resistor whose resistance value will depends upon the history of current passed in it [22].

When a memristor is excited with postive voltage, the conductivity increases with decrease in resistance on the other hand when a negative potential is applied the resistance increases. If the voltage or potential is turned off, the memristor will remains its last value of resistance [23]. If Memristor is used as a memory element the high resistance state will be logic 1 and low resistance wil be logic 0 [24].

1.2. Schematic representation of Memristor Emulator

The Figure 4 shows the block diagram of Memristor Emulator. The inverting amplifier circuit is one whose ouput is 180^0 out of phase with the input due to negative feedback. The ouput of inverting amplifier is fed to a voltage to current converter with grounded load. The V-I converter converts the voltage interms of a current which should drive thr RC parllel circuit. The Values of Resistor 10KΩ and Capacitor 1µF are to be assumed for the anlaysis of memristor emulator circuit.

From Equation (4) AD633JN is a four-quadrant analog multiplier whose result is a product of two outputs from R and C respectively. Where X and Y are differential inputs with a high impedance summing input (Z) and one output (W) the low impedance output voltage is a full scale 10 V provided by a Zener diode [19]. Hence output can be represented by:

$$w = \frac{(X1-X2)(Y1-Y2)}{10V} + Z \quad (4)$$

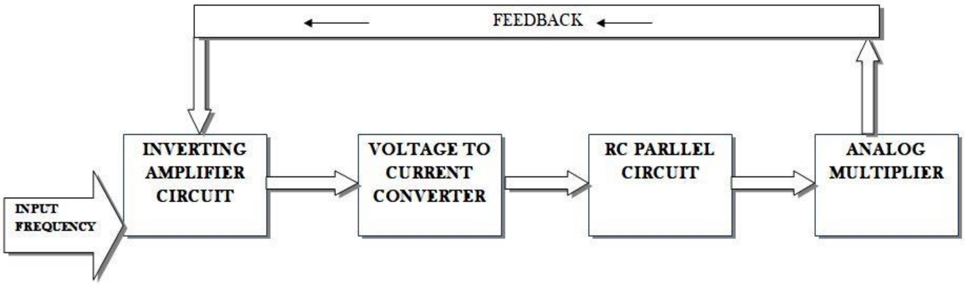

Figure 4. Block Diagram of Memristor Emulator

1.3. Basic Memristor Emulator Circuit

Basic Memristor Emulator Model in Figure 5, voltage at the input :

$$Vin = (Rs \times Iin) + Vx \quad (5)$$

From Equation (5), where I_{in} is the input current,$R_s$is the resistance at the input of inverting terminal Vx is the voltage applied to the non-inverting terminal of the op Amp.Here the voltage Vx is proportional to input current then consider:

$$Vx = m \times Iin \quad (6)$$

Then;

$$Vin = (Rs \times Iin) + (m \times Iin) \quad (7)$$

Rewritting the equation $Vin = (Rs + m)\ Iin$ (8)

Where m is the proportional coefficient and the input resistance is $(Rs + m)$ the value of m can be controlled by the time integral of input current Iin. So, the above fig. acts like a memristor. To emulate Vx the components resistor, capacitor and multiplier are used [19].
We can write Vx as:

$$Vx = \frac{q}{c} \times R3 \times Iin \quad (9)$$

Substitute Vx in Vin

$$\text{Therefore } Vin = \left\{Rs + \frac{q}{c} \times R3 \right\} \times Iin \tag{10}$$

From the equation (10) we can say the input resistance increases proportionally to the time integral of current at input with offset Rs. Rs is a fixed part and $\frac{q}{c} \times R3$ is a vaiable part. We can call this as incremental memristor emulator circuit [19].

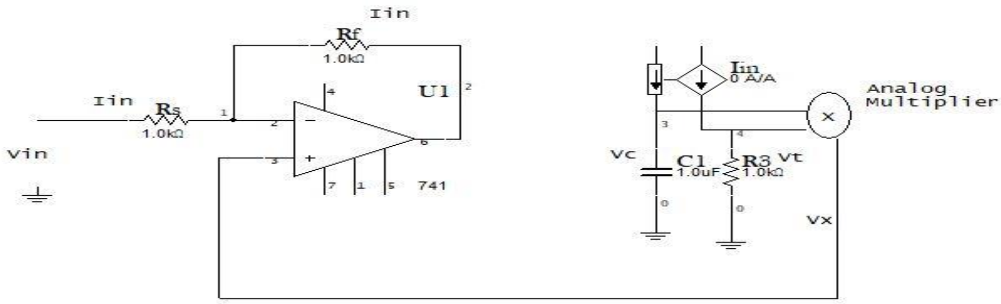

Figure 5. Basic Memristor Emulator Model

2. METHODOLOGY

2.1. Realization of Memristor using MULTISIM

The Figure 6 shows a memristor emulator in multisim assuming the values of resistances for op Amp are 1KΩ and for RC circuit R=10KΩ and C=1μF.For linear characteristics the memristor is a linear resistor the voltage to current relation is a straight line since both are directly proportional to each other [19]. Memristor with fixed value M is a linear resistor. If M is variable it can act as a memory function, so a non linear component is necessary as a converted component. A Diode 1N1199C can convert the fixed value M to variable M [25]. A complete representation of a simple memristor emulator is shown in the Figure (6). In practice the value of Rs is considered a small value around 1KΩ. When an input is applied to a memristor emulator it is converted in terms as a input current I_{in} with resistor R_s and op Amp U1 via virtual ground concept. A Grounded load voltage to current converter provides an output current. The output current from V-I converter is driven to a parallel RC circuit where a charge in the capacitor takes place $Vc = \frac{q}{c}$ with $Vt = R3 \times Iin$. The quadrant analog multiplier multiplies the voltage Vc and Vt with output product$Vx = \frac{q}{c} \times R3 \times Iin$. During the charge emulator stores its value as a function of memory resistor [19].

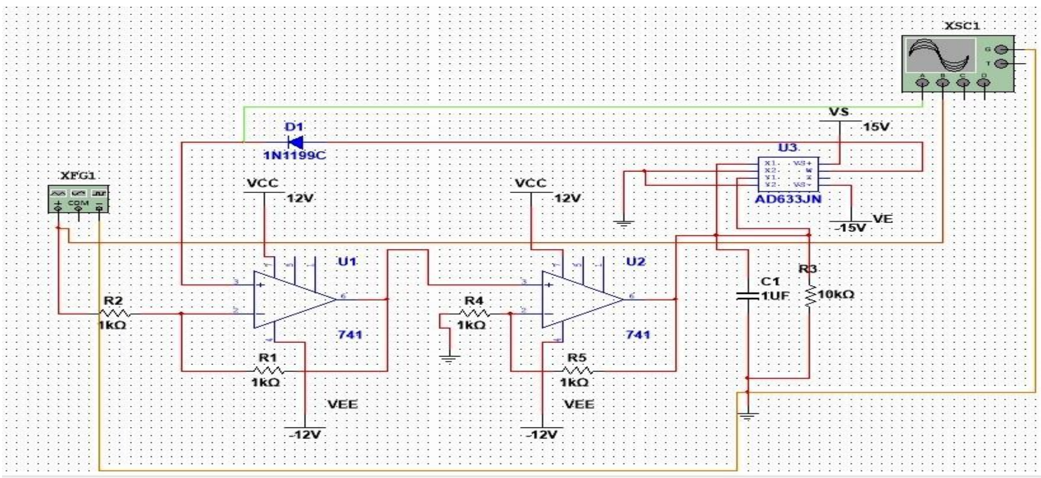

Figure 6. Realization of Memristor using MULTISIM

3. RESULT ANALYSIS

3.1. Memristor Emulator Simulation Graphs

The Figure 7 shows a Simulation Graph result for frequency F=1 Hz, in which red color indicates the input sine wave form with input 10Vpp amplitude. For frequency F=1Hz which is almost a DC component and shows a linear relationship between input and output (blue color) with respect to time.

The Figure 8 shows a Simulation Graph result for frequency F=100 Hz, the output wave is a low level clamped signal which shows a slightly non-linear relationship with input ac component.

The Figure 9 shows a Simulation Graph result for frequency F=500 Hz, the output wave shows a non-linear relationship with an input. The corresponding input and output waveforms with respect to time for both A/B (input/output) and B/A (output/input) are shown in Figure 10 and 11 respectively.

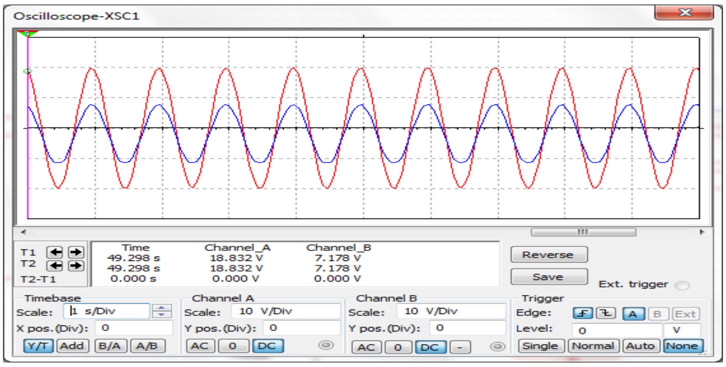

Figure 7. Memristor Emulator Simulation Graph for the frequency F=1Hz

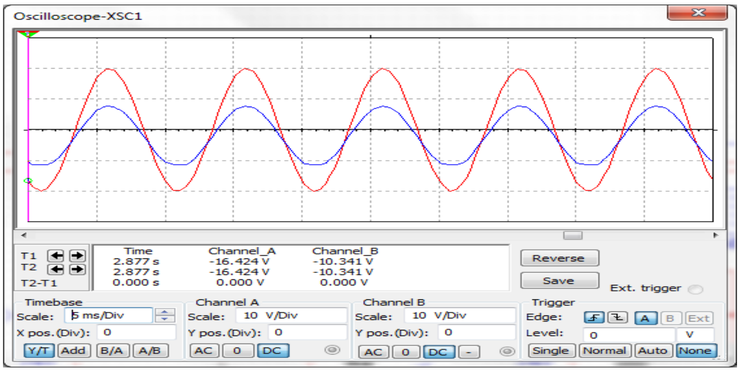

Figure 8. Memristor Emulator Simulation Graph for the frequency F=100Hz

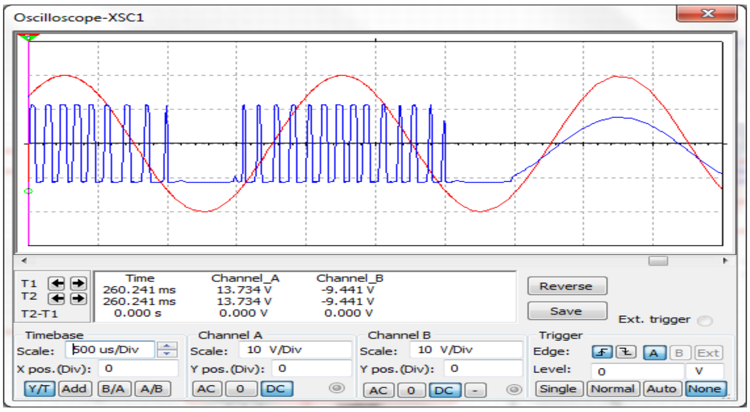

Figure 9. Memristor Emulator Simulation Graph for the frequency F=500Hz

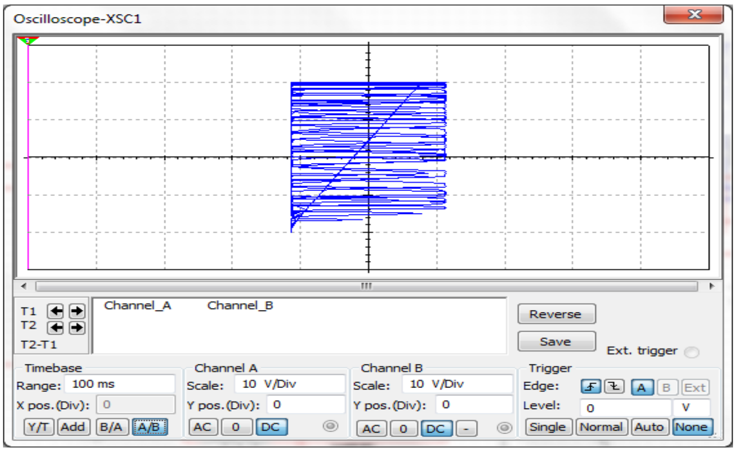

Figure 10. A/B (Output/Input)

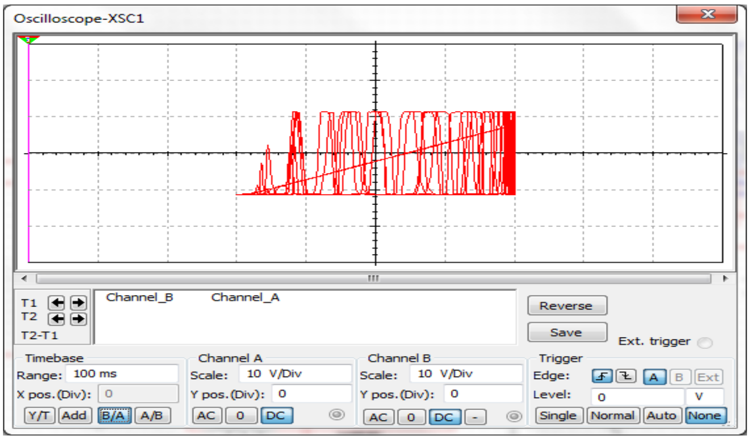

Figure 11. B/A (Output/Input)

The Figure 12 shows a Simulation Graph result for frequency F=1 KHz, the output wave shows a non-linear relationship with an input. The corresponding input and output waveforms with respect to time for both A/B (input/output) and B/A (output/input) are shown in Figure 13 and 14 respectively.

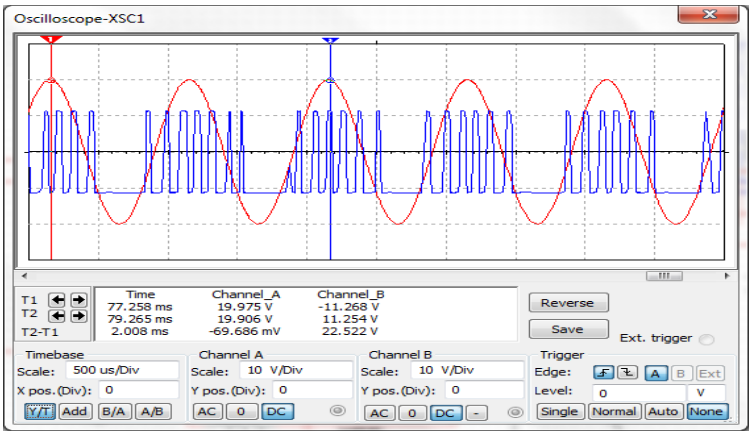

Figure 12. Memristor Emulator Simulation Graph for the frequency F=1 KHz

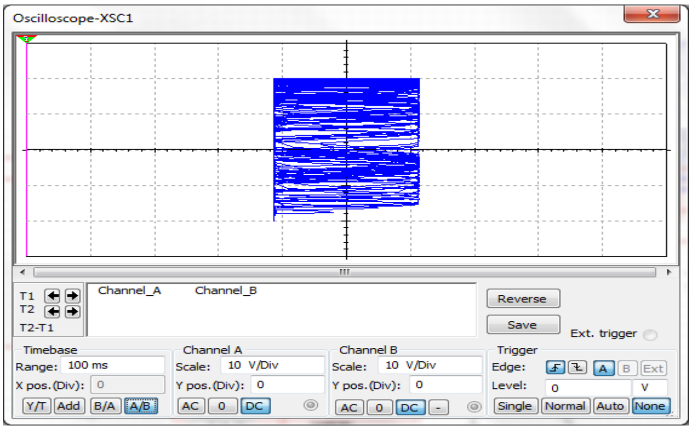

Figure 13. A/B (Output/Input)

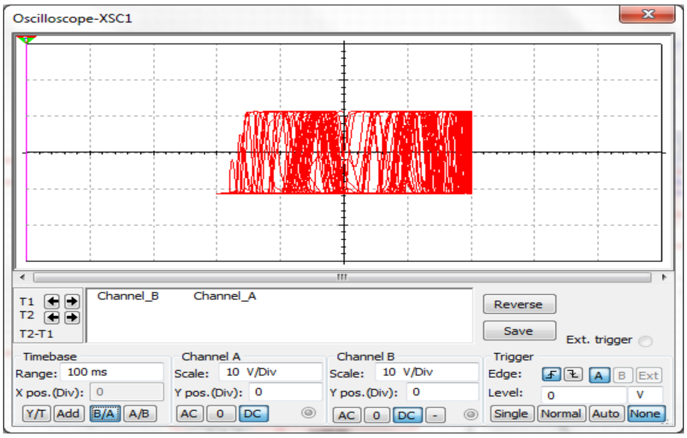

Figure 14. B/A (Output/Input)

From the above experiment for the different frequencies from 1Hz to 1 KHz sinusoidal input the output waveform becomes nonlinear.

4. CONCLUSION

The nonlinear passive element called Memristor is used and an emulator has been designed. The linear and nonlinear characteristics of the device are studied and also simulation work has been carried out using multisim. Indeed no physical memristor device was not available in market, Multisim is used and emulator circuit has been designed and device characteristics are analyzed. A simulation result depicts the effectiveness of the memristor. This study explicitly shows that memristor is effective in all aspects of linear and nonlinear characteristics.

REFERENCES

[1] Radwan A.G., Fouda M.E. (2015) *Memristor: Models, Types, and Applications. In: On the Mathematical Modeling of Memristor, Memcapacitor, and Meminductor.* Studies in Systems, Decision and Control, vol 26. Springer, Cham
[2] L. Chua, "Memristor-The missing circuit element," in *IEEE Transactions on Circuit Theory*, vol. 18, no. 5, pp. 507-519, September 1971. doi:10.1109/TCT.1971.1083337
[3] D. B. Strukov, G. S. Snider, D. R. Stewart, R. S. Williams, "The missing memristor found", Nature 453, pp. 80-83, 2008.
[4] A L. Fitch, H. H. C. Iu, X. Y. Wang, V. Sreeram and W. G. Qi, *"Realization of an analog model of memristor based on light dependent resistor,"* 2012 IEEE International Symposium on Circuits and Systems, Seoul, 2012, pp. 1139-1142.

[5] S. M. A. B. Mokhtar and W. F. H. Abdullah, "Re-model fabricated memristor behavior in LT-SPICE and applied in logic circuit," *2014 IEEE Symposium on Computer Applications and Industrial Electronics (ISCAIE)*, Penang, 2014, pp. 106-110.
[6] Isaac Abraham, "The case for rejecting the memristor as a fundamental circuit element", *Scientific Reports* volume 8, Article number: 10972 (2018).
[7] Danilin, S. N., Shchanikov, S. A., & Galushkin, A. I. (2015, May). The research of memristor-based neural network components operation accuracy in control and communication systems. "*In 2015 International Siberian Conference on Control and Communications (SIBCON)"* (pp. 1-6). IEEE.
[8] Itoh, M., & Chua, L. O. (2008). Memristor oscillators. *International journal of bifurcation and chaos,* 18(11), 3183-3206.
[9] Muhammad Taher Abuelma'atti, Abdullah Yousef Alnafisa, "A memristor-based chaotic-masking for analog spread-spectrum communication", *Indonesian Journal of Electrical Engineering and Computer Science,* volume 14, issue 2, pages 966-971, 2019.
[10] Julius Han Loong Teo, Noor Alia Nor Hashim, Azrul Ghazali, Fazrena Azlee Hamid, "Ring oscillator physically unclonable function using sequential ring oscillator pairs for more challenge-response-pairs", *Indonesian Journal of Electrical Engineering and Computer Science,* volume 13, issue 3, pages 892-901, 2019.
[11] Noor Alia Nor Hashim, Julius Teo Han Loong, Azrul Ghazali, Fazrena Azlee Hamid, "Memristor based ring oscillators true random number generator with different window functions for applications in cryptography" , *Indonesian Journal of Electrical Engineering and Computer Science,* volume 14, issue 1, pages 201-209, 2019.
[12] Julius Han Loong Teo, Noor Alia Noor Hashim, Azrul Ghazali, Fazrena Azlee Hamid "Configurations of memristor-based APUF for improved performance" *Bulletin of Electrical Engineering and Informatics,* volume 8, issue 1, pages 74-82, 2019.
[13] H. V. Gururaja Rao, Nagesh Prabhu, R. C. Mala, "Emulated reactance and resistance by a SSSC incorporating energy storage device", *International Journal of Electrical and Computer Engineering,* volume 9, issue 2, pages 840-850, 2019.
[14] Srinivasan, C. R., et al, "A Review on the Different Types of Internet of Things (IoT)" *Journal of Advanced Research in Dynamical and Control Systems*, volume 11, Issue-1 pages: 154-158, 2019.
[15] Rajesh, B., et al. "A study on onion omega 2 plus IOT device in weather application." *Journal of Advanced Research in Dynamical and Control Systems* Volume-10, Special issue-3, Pages: 196-200, 2019.
[16] Adhitya Bhawiyuga, Dany Primanita Kartikasari, Kasyful Amron, Ocki Bagus Pratama, Moch. Wildan Habibi, "Architectural design of IoT-cloud computing integration platform" *TELKOMNIKA (Telecommunication, Computing, Electronics and Control),* volume 17, issue 3, pages 1399-1408, 2019.
[17] Syed Farid Syed Adnan, Mohd Anuar Mat Isa, Habibah Hashim, "Testbed versus simulation approach on RF communication with AAβ asymmetric encryption scheme on internet of things devices", *Indonesian Journal of Electrical Engineering and Computer Science,* volume 14, issue 1, pages 353-359, 2019.
[18] Vinoth Jonathan Nagarajah, Hui Jing Lee, King Guan Tan, Nathawat Khunprasit, "Performance analysis of supercapacitors for transportation industry" *Indonesian Journal of Electrical Engineering and Computer Science,* volume 13, issue 3, pages 1031-1038, 2019.
[19] Kim, Hyongsuk & Pd. Sah, Maheshwar & Yang, Changju & Cho, Seongik & Chua, Leon. (2012). *Memristor Emulator for Memristor Circuit Applications.* Circuits and Systems I: Regular Papers, IEEE Transactions on. 59. 2422-2431.
[20] S. M. A. B. Mokhtar and W. F. H. Abdullah, "Memristor to control delay of delay element," *2014 IEEE International Conference on Semiconductor Electronics (ICSE2014)*, Kuala Lumpur, 2014, pp. 483-486. doi:10.1109/SMELEC.2014.6920903
[21] Rajdevinder kaur sidhu, Tarandip Singh "Different models of Memristor" *International Journal of Engineering & Research & Technology (IJERT)* ISSN:2278-0181 Vol.4, Issue 06, June-2015
[22] O. A. Olumodeji, A. P. Bramanti and M. Gottardi, "Memristor-based pixel for event-detection vision sensor," *2015 IEEE SENSORS*, Busan, 2015, pp. 1-4. doi:10.1109/ICSENS.2015.7370688
[23] S. M. A. Mokhtar, W. F. H. Abdullah, K. A. Kadiran, R. Rifin and M. Omar, "Write and read circuit for memristor analog resistance switching," *2017 IEEE 8th Control and System Graduate Research Colloquium (ICSGRC)*, Shah Alam, 2017, pp. 13-16. doi:10.1109/ICSGRC.2017.8070559
[24] S. Smaili and Y. Massoud, "Analytic modeling of memristor variability for robust memristor systems designs," *2014 IEEE International Symposium on Circuits and Systems (ISCAS)*, Melbourne VIC, 2014, pp. 794-797. doi:10.1109/ISCAS.2014.6865255
[25] Dehua Song1, Xiang Ren1, Mengfei Lv1, Mengmeng Li1, Haiyang Zhou1, Yunxiao Zu2 "The Realization an3d Working Conditions of Memristor Based on Multisim*" Journal of Computer and Communications*, 2013, 1, 5-10.