Low Cost High Voltage Generation: A Technique For Educational Laboratory

Chitra Sharma[1], A. K. Jhala[2], Manish Prajapati[3]

Abstract— **In this paper a method is discussed to generate high voltage DC up to 110kV using Cockroft-Walton Voltage Multiplier for study and research at educational laboratory. As High Voltage DC (HVDC) transmission is becoming more popular in the present scenario of bulk power transmission over long distance transmission, it is required to study the testing of various insulation materials at laboratory level in under graduate and post graduate course curricula. Since, generation and handling of high voltage is very dangerous and required skilled personnel in the laboratory. In addition, it is very much costly. Apart from the basic requirement, a precise development of electrical circuit is required in order to generate high voltage in the laboratory. In this paper cost effectiveness and the basic circuit structure is developed with the mathematical and graphical representation. Also the model of high voltage generation circuit is studied mathematically and simulated its result in MATLAB™.**

Index Terms— **Cockroft Walton Multiplier Circuit, Grienacher Multiplier Circuit, High Voltage Generation, High Voltage DC transmission, Insulation Testing.**

I. Introduction

CURRENT scenario of power transmission is changing as to improve the power transfer capability and reducing the losses. Many studies have been done to improve the power transfer by using the high voltage DC transmission. Also in developing country prevent power theft is also a big issue. National Electricity Board of different country made a rules and regulation regarding the voltage level to prevent power theft. As IEEE 519-1992 has a standard for power quality and power transfer voltage level at different voltage level. As many European nation made their voltage level greater than low voltage level to medium voltage level as to identification of faults and various other cause. High voltage is becoming integrated part of electrical power system along with x-ray generation, medical advancement and other field [1]. In year 1930 J. D. Cockcroft and E.T.S. Walton had proposed circuitry for generation for high voltage using Grienacher Voltage Doublers circuit for the study of high voltage generation for positive ion emission from the hydrogen and other element [2]. In their successive submission they had presented the application of Cockroft Walton Voltage Multiplier (CWVM). Insulation testing of cable, disc insulator and other electrical insulator draws heavy current if they are tested under the high voltage AC. To perform withstand test the high voltage DC is much more suitable than the High Voltage AC as it draws very low current in order of few [mA]. High Voltage can be divided in various categories:

- AC high Voltage, variable frequency, has RMS , AVG and Peak Value
- DC high Voltage, fixed, low frequency, has only Average value
- Impulse Voltage, Peak value only [1,4,5].

High Voltage Engineering is very important subject to deal in curricula designed by AICTE and other technical community to be studied in graduate and postgraduate level. Since the installation and handling of high voltage laboratory require high investment including the skilled personnel to handle it. In this paper low cost circuit design is presented which can be experimented in laboratory. In [3] author developed model to employ surface mount technology to build a very small size energy source for photomultiplier tube (PMT). As due high applicability and reduced loss level high voltage study now not out of reach of educational laboratory. In addition, as high voltage becoming popular in research field, basic development in study is required.

Structure of this paper is given as section II deals with the generation technique for high voltage. In this section mathematics involved in high voltage generation using CWVM is presented. Whereas, section III deals with the design criteria for seven stage CWVM circuit. In section IV SIMULINK validation of mathematical model is presented. Once the result is generated section V represents the conclusion of the work.

II. High Voltage DC Generation

In traditional system high voltage is generated in well established laboratory where the grounding and other safety concern are well developed. Nevertheless, present status of economical issue and due to lack of skilled staff it very difficult to operate and demonstrate the experiments related to high voltage. General structure of laboratory installation requires huge investment. In order to make it economical and produce the well educated engineers it is mandatory to perform the high voltage. At present, high voltage laboratory are success at only those places where funding are proper and skill staff are available.

Despite of above mentioned issue it is very important to understand the behavior and generation of high voltage

Manuscript received Nov, 2015.

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ISSN: 2278 – 7798

theoretically.

High Voltage DC are generated by various methods:

- Van-De-Graaf Generator
  - Its principle is based on Electrostatic generator as like electromagnetic generator whereas conductors are moving and /or rotating along a magnetic field. Instead there is a charge collector built inside a tank filled with ionized charge.
- Grienacher Voltage Double Circuit
  - It is a two stage rectification circuit and requires high stable devices if voltage more than 10kV is handled.
- Cockroft-Walton Votlage Multiplier
  - It is a basically development of multistage Grienacher Circuit.

Cockroft Walton Voltage Multiplier is very well developed high voltage generation technique and can be used at laboratory level. It is clear that Van-De-Graaf Generator needs a large space while Grienacher Voltage Doubler is not suited to handle voltage level more than 10kV.

Fig. 1 shows the structure of Grienacher Circuit for further extension as CWVM.

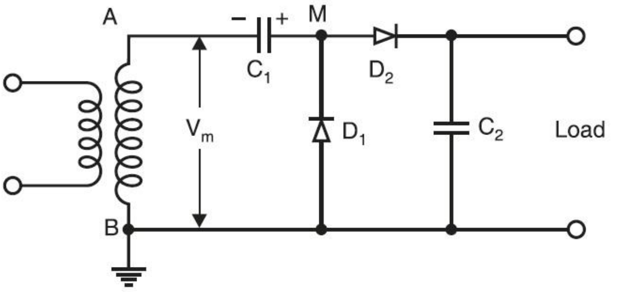

Figure 1 Grienacher Voltage Doubler Circuit

The rating of transformer depends on the output voltage level. As output voltage increases the secondary side needs to be in the proper ratio. In addition, there is chance of magnetic saturation of the transformer as secondary side DC current increases.

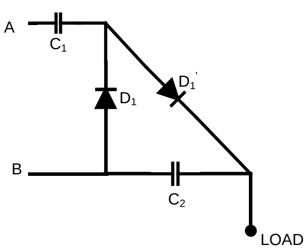

Figure 2 Single Stage of Grienacher Circuit.

In Fig. 2 single stage of Grienacher Voltage doubler circuit is given which is soul of the Cockroft Walton Voltage multiplier.

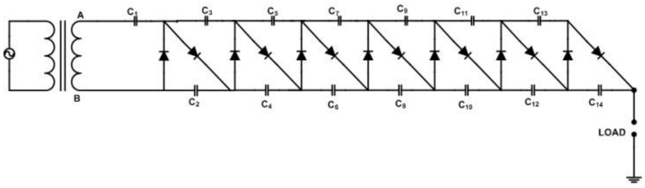

Figure 3 Seven Stage CWVM Circuit

A-B is the secondary of transformer while the D_1 and D_1' is complementary switches, which operates in alternate cycle of supply.

III. Design of Multiplier Circuit

Fig. 3 shows the complete stages of CWVM as to generate 110kV. In above figure 2, single stage is shown as to employ on seven stage multiplier. A high voltage transformer is taken to provide very low current on secondary. This circuit is consisting of series parallel combination of diode to achieve the blocking voltage as required. Also, the rating of capacitor is matched to withstand the voltage level in a each stage. Cockroft-Walton multiplier has different construction. In this paper half wave "Cockroft-Walton" multiplier is shown.

$$2\delta V = q\sum_{n=2}^{2n}\frac{1}{C_n} \qquad (1)$$

$$q = IT \qquad (2)$$

$$q = \frac{I}{f} \qquad (3)$$

δV is amount of ripple generated by the system, since it passes through C_2, C_4, C_6… only because these capacitor columns is known as *smoothening column* as voltages through these circuit remain constant. Whilst the voltage through C_1, C_3, C_5… oscillates in same manner as supply varies that is the reason it is known as *oscillating column.* 'q' is amount of charge injected to smoothening circuit. For n stage total ripple is given by;

$$2\delta V = q\left(\frac{1}{C_{2n}} + \frac{2}{C_{2n-2}} + \frac{3}{C_{2n-4}} + \frac{4}{C_{2n-6}} + ... + \frac{n}{C_2}\right) \qquad ...(4)$$

From above it is clear that the voltage ripple generally depend on the lowest capacitor hence size of capacitor at lowest end can be kept smaller. However, due to loading effect and other un-avoidable condition this may create a severe damage to the system hence it is advisable to keep this value identical.

$$C_{2n} = C_{2n-2} = C_{2n-4} = C_{2n-6} = ... = C_2 = C$$

As putting the above identical values equation (4) can be written as

$$\delta V = \frac{I}{2fC}\left(\frac{n(n+1)}{2}\right) = \frac{I}{fC}\left(\frac{n(n+1)}{4}\right) \qquad (5)$$

It is very much obvious from the equation (5) that the voltage ripple is constant and depends on the number of stage. As number of stages increases the ripple content is increases proportional to $n(n+1)$. Variation of ripple with number of stage is given in figure 4. As it is clear that the

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variation is non-linear after n=10 and n=11 stages, still it is comparable that till lower stages and ripple can be linearised.

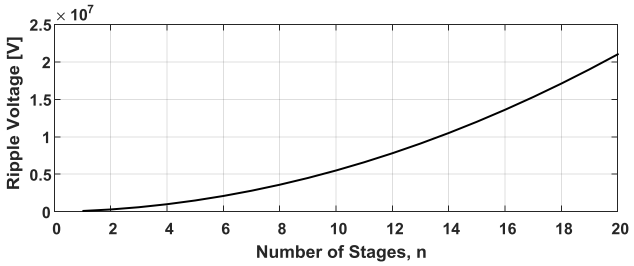

Figure 4 Variation of Ripple Voltage with number of stages in CWVM.

In addition, ripple is function of number of stages and number switching frequency for a fixed capacitor desing. Hence, varying frequency ripple can be reduced and can be treated as high frequency swithching of CWVM network. For pertaining the same threshold figure 5 provides information regarding variation of ripple with respect to the various frequency level. It is obvious that the system is fixed for a installation where capacitance can not be altered hence the variation of capacitance for a fixed circuit is not possible. However, for design consideration variation of capacitor can also be seen with various frequency combination with optimised value of capacitance and operating frequency.

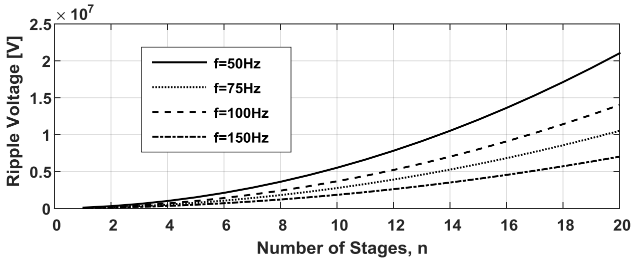

Figure 5 Ripple Voltage in CWVM as different Frequency Level

In the present work, diode drop is neglected for the sake of simplicity and to reduce the complexity of the circuit equations. Also, parasitic effect of diode and capacitor is neglected as its contribution is very small.

There are two modes of operation of CWVM viz. *no load operation*, and *operation under loaded condition.* When load is applied there will be some drop due to internal behavior and load applied. That drop is considerably high and reduces the output voltage in a great manner.

Total drop ΔV is given by:

$$\Delta V = \Delta V_n + \Delta V_{n-1} + \Delta V_{n-2} + ... + \Delta V_1 \qquad (6)$$

On solving for each stage drop is given by the;

$$\Delta V = \frac{I}{2fC}\left(\frac{2}{3}n^3 + \frac{n^2}{2} - \frac{n}{6}\right) \qquad (7)$$

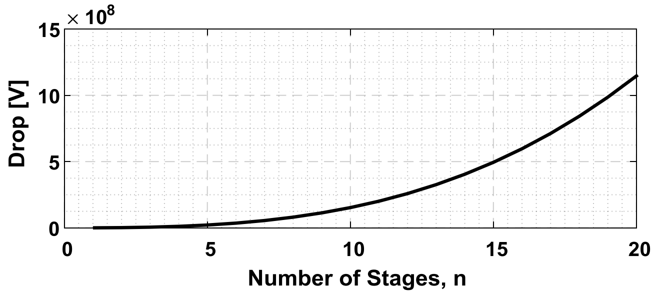

Figure 6 Variation of Drop Voltage for a fixed frequency

In Fig. 6 drop characteristic is given which is also nonlinear in nature. Drop can be reduced by using and minimizing the equation (7) with respect to either operating frequency or the capacitor voltage. For a particular level of ripple and drop one can optimize the frequency and capacitor value with respect to fixed stage.

$$n_{opt} = \sqrt{\frac{V_{\max} fC}{I}} \qquad (8)$$

As to get a fixed stage of output voltage with constant frequency and capacitor value, optimal number of stage can be calculated. Again, this equation number (8) is considered when number of stages is assumed, $n \geq 5$.

Table I Parameter Value for Simulation

Parameter	Numerical Value [unit SI]
Input Voltage to Primary of X'mer V_P	***230[V]***
Secondary Voltage	***10000 [V]***
Supply Frequency, f	***50 [Hz]***
Capacitor, C	***100 [nF]***
Number of Stages, n	***7***

IV. Simulation And Results

With values given in table I, one can simulate this model with a fixed rating of all elements. Voltage drop through diode is neglected.

ISSN: 2278 – 7798

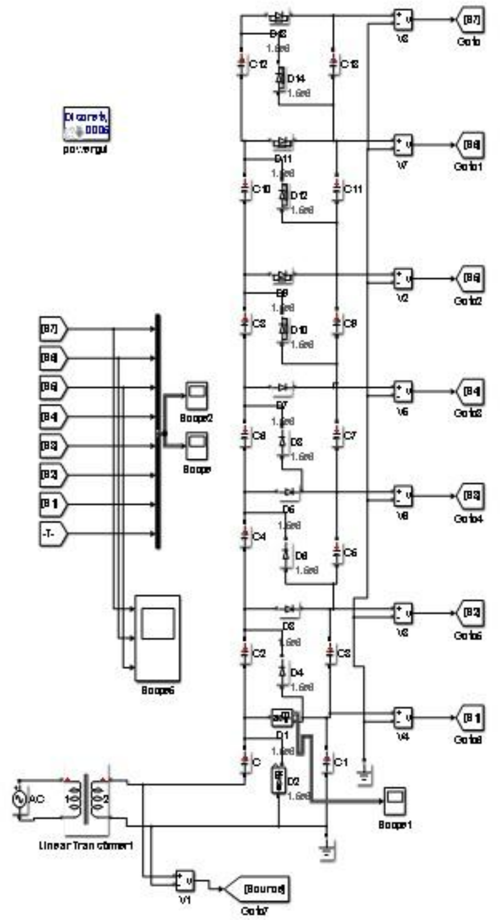

Figure 7 Circuit Arrangements in Simulation

Fig. 9 shows the simulation arrangement in this figure scopes are the virtual oscilloscope where the visualization of voltages are taken. It can be used as recording purpose also.

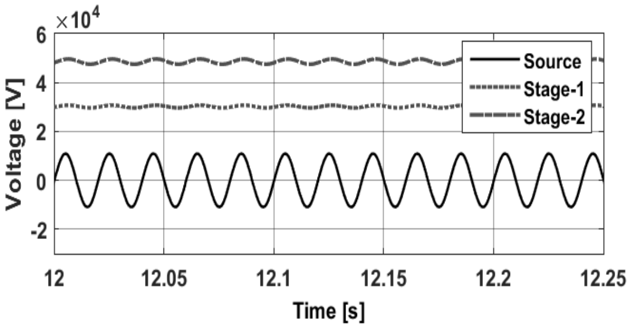

Figure 8 Voltages of Source and Stage-1, 2

Simulation shown in Fig 7 is simulated in MATLAB™ environment for various numbers of runs and with 20 seconds run till the stable output is not achieved. After proper stable condition Fig. 9 is plotted for the stage output of stages 5, 6, & 7. The darkest waveform is stage 7 output with 100kV output level and some ripple content. Ripple content in final stage is high comparable to lower stage because as discussed in previous section voltage double not only doubles the maximum voltage it also doubles the ripple content. It is very difficult to estimate the ripple content in the actual hardware circuit. But the amount of ripple can be observed in Fig 10 for the stage-5, stage-6 and stage-7.

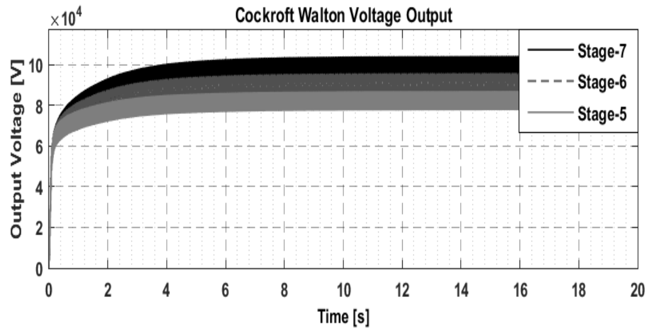

Figure 9 Output of Final Three Stages

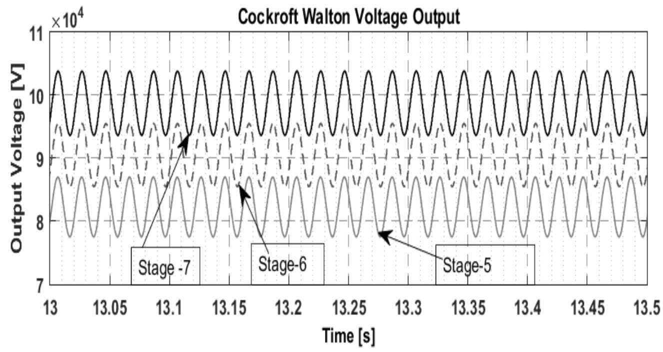

Figure 10 Ripple Voltage Level of Output Stages

It is clear from Fig 10 that the ripple is higher in the upper stages as compared to the lower stages. One can design such a variable capacitor for these stages so that the estimation and prediction of ripple can be observed and accordingly value can be set for a fixed or variable frequency operation.

In the present work to support the analytical point as the ripple gets double in each stage one can observe in Fig. 8 and Fig. 9. In Fig. 8 Stage-1 and 2 has very less ripple as compared to Fig. 10. Also, source voltage has stable frequency and response is observed in the Fig 8 itself.

Application of high voltage in laboratory has various objectives to accomplish as very important and prior aim is to demonstrate the various impact of high voltage by connecting as sphere gap or rod-gap arrestors to the load end of CWVM unit. Secondly, this high voltage can be the charging voltage supply for a medium level impulse generator. Moreover, this voltage level can be used to test withstand voltage level of any insulating media.

V. CONCLUSION

In this paper we accomplished a simulation waveform and analytical generation of high voltage for the laboratory purpose. Generation of High Voltage at laboratory up-to 100kV is designed and simulated for laboratory level. In this work effect of diode drops and parasitic resistance of capacitor is neglected. In future this work can be modeled with all non idealities and derivative effect of capacitor. Also in this paper frequency of operation is kept constant, by use of cyclo-converter or any other frequency changing device can be employed for the reduction of ripple. Since the selection of capacitor and frequency is based on available supply and cost effectiveness is considered. Moreover, a soft-computing can be used to optimize the circuitry with various constraints and parameter limitation.

ISSN: 2278 – 7798

ACKNOWLEDGMENT

This work is part of Master thesis, under the guidance of A. K. Jhala and Manish Prajapati, at RKDF College of Engineering Bhopal, affiliated to RGPV, Bhopal.

REFERENCES

[1] Kuffel, E. and M. Abdullah, 1984. High Voltage Engineering. Pergamon Press, Oxford.

[2] J. D. Cockroft and E. T. S. Walton, "Experiments with High Velocity Positive Ions," *Proceeding of Royal Society of London, Series A, Containing Papers of a Mathematical and Physical Character*, vol. 129, no. 811, pp. 477-489, 1930.

[3] Spencer, D.F., R. Aryaeinejad and E.L. Reber. "Using the Cockroft-Walton Voltage Multiplier Design in Handheld Devices." *Idaho National Engineering and Environmental Laboratory*, P.O. Box 1625, Idaho Falls, ID 83415

[4] Khan, N., 2004. Lectures on Art and Science of High Voltage Engineering. Published in Pakistan

[5] Mazen, A.S. and R. Radwan, 2000. High Voltage Engineering Theory and Practice. Sec. Edn. Revised and Expanded, Marcel Dekker, Inc. Am. J. Applied Sci., 3 (12): 2178-2183, 2006 2183

[6] Aintablian, H.O. and H.W. Hill, 1994. A new single phase AC to DC harmonic reduction converter based on the voltage –doubler circuit. Department of Electrical and Computer Engineering, Ohio University, Athens, IEEE.

[7] John, C.S., 1993. Circuit topologies for single phase voltage –doublers Boost rectifiers. IEEE Trans. Power Elect., 8: 4.

[8] 10. Yamamoto, I., K. Matsui and F. Ueda, 2000. A power factor correction with voltage doubler rectifier. Chubu University, Dep. Electrical Eng. Japan, IEEE.

[9] Zhang, M., N.L. Iaser and F. Devos. An optimized design of an improved voltage Tripler. IEF, AXIS, University of Paris, 91405 Orsay, France.

[10] Zhang, M., N. Liaser and F. Devos, 2002. Experimental results of an optimized voltage Tripler. IEF, AXIS, University of Paris, 91405 Orsay, France.

[11] J.S.Burgler, "Theoretical performance of voltage multiplier circuits" IEEE.Journal of solid state circuits publications, vol.6,issue3, pp132-135, June 1971.

[12] D. Maksimovic, S. Cuk, "Switching Converters with Wide DC Conversion Range", IEEE Transactions on Power Electronics, Vol. 6, No. 1, pp. 151-157, January 1991.

[13] F. L. Luo, H. Ye, "Positive Output Super-Lift Converters", IEEE Transactions on Power Electronics, Vol. 18, No. 1, pp. 105-113, January 2003.

[14] K. C. Tseng, T. J. Liang, "Novel high-efficiency step-up converter", IEE Proc.-Electr. Power Appl., Vol 151, No. 2, pp. 182-190, March 2004.

[15] C. Y. Inaba, Y. Konishi, M. Nakaoka, "High-frequency flybacktype soft-switching PWM DC-DC power converter with energy recovery transformer and auxiliary passive lossless snubbers", *IEE Proc.-Electr. Power Appl.*, Vol. 151, No. 1, pp. 32-37, January 2004.

[16] F. Hwang, Y. Shen, S. H. Jayaram, "Low-Ripple Compact HighVoltage DC Power Supply", *IEEE Transactions on Industry Applications*, Vol. 42, No. 5, pp. 1139-1145, Sept./Oct. 2006.

[17] A. Shenkman, Y. Berkovich, B. Axelrod, "Novel AC-DC and DCDC Converters with a Diode-Capacitor Multiplier", *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 40, No. 4, pp. 1286-1293, October 2004.

[18] K. Ogura, E. Chu, M. Ishitobi, M. Nakamura, M. Nakaoka, "Inductor Snubber-Assisted Series Resonant ZCS-PFM High Frequency Inverter Link DC-DC Converter with Voltage Multiplier", *Power Conversion Conference (PCC'2002), Osaka (Japan)*, 2-5 April, 2002, Vol. 1, pp. 110 – 114.

[19] "Experiment 19: Blaze Labs Resonant Multipliers", *Blaze Labs Research*, 12 September 2005, Internet paper, available: http://www.blazelabs.com/e-exp19.asp, accessed on 30/11/2006.

[20] M.M. Weiner, "Analysis of Cockcroft-Walton Voltage Multipliers with an Arbitrary Number of Stages", *The Review of Scientific Instruments*, Vol. 2, No. 2, pp. 330-333, February 1969.

[21] "Experiment 15: Cockroft-Walton Multiplier", *Blaze Labs Research*, 30 August 2005, Internet paper, available: http://www.blazelabs.com/e-exp15.asp, accessed on 02/11/2015.

[22] M. Julian, "Cockroft-Walton Optimum Design Guide v2.0", 10 August 2005, Internet paper, available: http://www.blazelabs.com/ CWdesign.pdf, accessed on 02/11/2015.

[23] M. Khalifa, "High-Voltage Engineering, Theory and Practice", Chapter 16, *Electrical Engineering and Electronics, A series of Reference Books and Textbooks*, №63, Marcel Decker Inc., March 1990.

[24] WALUYO, SYAHRIAL, SIGIT NUGRAHA3, and YUDHI PERMANA, "MINIATURE PROTOTYPE DESIGN AND IMPLEMENTATION OF MODIFIED MULTIPLIER CIRCUIT DC HIGH VOLTAGE GENERATOR," International Journal of Electrical Engineering and Technology (IJEET), vol. 6, no. 1, pp. 01-12, January 2015.

[25] High Voltage Generation by using Cockcroft-Walton Multiplier," International Journal of Science, Engineering and Technology Research (IJSETR), Volume 4, Issue 2, February 2015, vol. 4, no. 2, pp. 256-259, February 2015

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ISSN: 2278 – 7798