VOLUME 6, ISSUE 1, JANUARY (2015) ISSN (PRINT) 0976-6545, ISSN (ONLINE) 0976 - 6553

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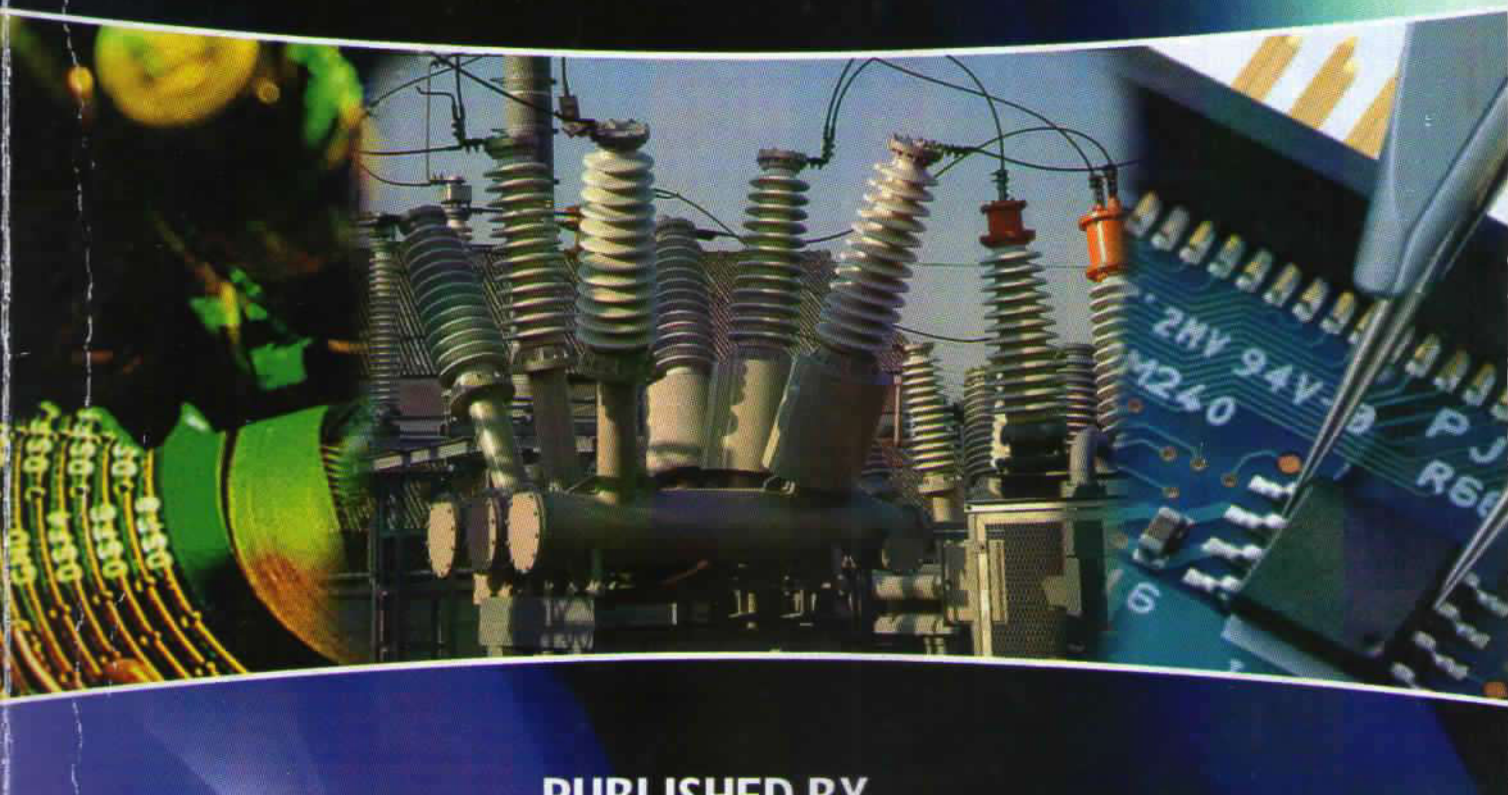

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ISSN Print: 0976-6545 **ISSN Online: 0976-6553**

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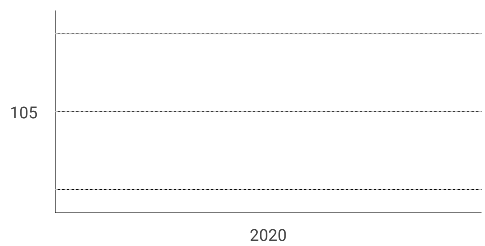

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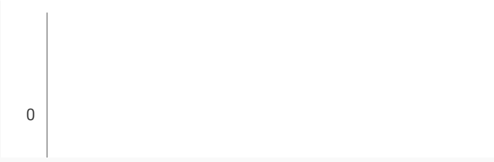

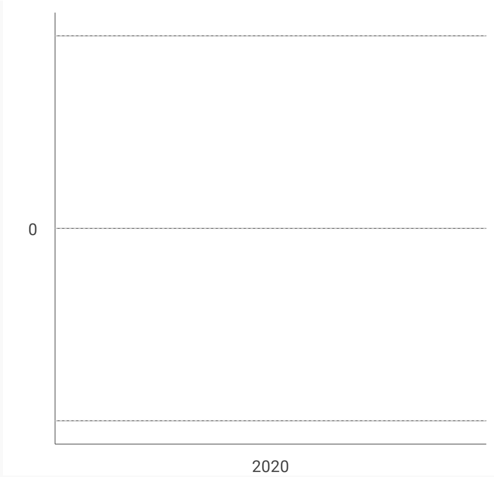

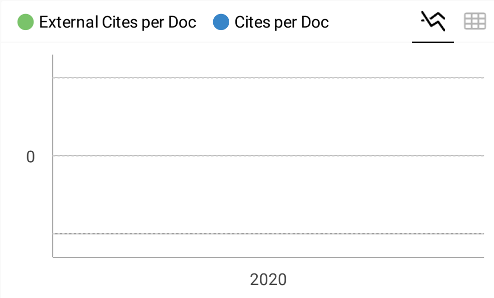

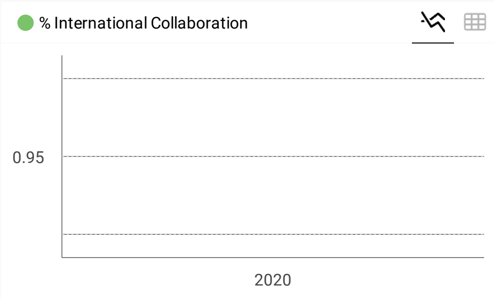

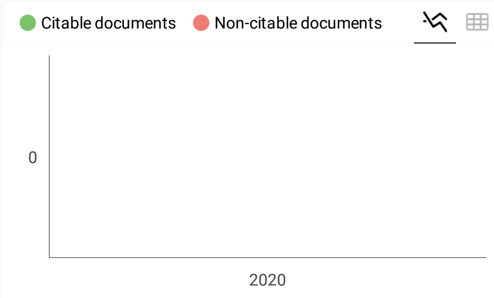

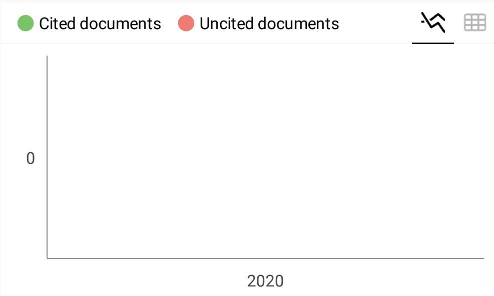

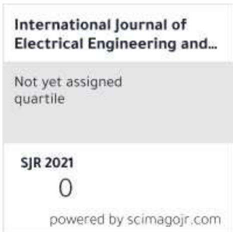

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MINIATURE PROTOTYPE DESIGN AND IMPLEMENTATION OF MODIFIED MULTIPLIER CIRCUIT DC HIGH VOLTAGE GENERATOR

WALUYO [1] ; SYAHRIAL [2] ; SIGIT NUGRAHA [3] ; YUDHI PERMANA JR [4]

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Article Id - 40220150601001, Pages : 1-12, Date of Publication : 14, January 2015

Abstract

DC high voltage is one of the means used in a variety of insulating material testing and laboratory equipment. In addition, direct current high voltage transmission lines are used in electrical power. Thus, the DC high voltage is very necessary existence. This study aimed to design and implement a miniature prototype DC high voltage generator with the modified multiplier circuits. In this design, the AC low voltage was rectified alternating first, and the DC voltage was multiplied by using the modified multiplier circuit. The circuit output voltages were DC high voltage forms. The DC output high voltages were measured by using a digital storage oscilloscope through a voltage divider. Thus, various DC high voltage waveforms could be measured and recorded by the storage oscilloscope and the data were transferred to the computer. In this design, it was realized four stages of dc high voltage multiplier, where it was yielded 6185 Volt dc with the input of 600 Volt rms ac, on the no load condition. The average ratio of the dc voltage to rms ac input voltage was 10.76. The average ripple of dc output voltages was 1.134% on the no load condition.

Keywords

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INTERNATIONAL JOURNAL OF ELECTRICAL ENGINEERING & TECHNOLOGY (IJEET)

ISSN 0976 – 6545(Print)
ISSN 0976 – 6553(Online)
Volume 6, Issue 1, January (2015), pp. 01-12
© IAEME: www.iaeme.com/IJEET.asp
Journal Impact Factor (2014): 6.8310 (Calculated by GISI)
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MINIATURE PROTOTYPE DESIGN AND IMPLEMENTATION OF MODIFIED MULTIPLIER CIRCUIT DC HIGH VOLTAGE GENERATOR

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ABSTRACT

DC high voltage is one of the means used in a variety of insulating material testing and laboratory equipment. In addition, direct current high voltage transmission lines are used in electrical power. Thus, the DC high voltage is very necessary existence.

This study aimed to design and implement a miniature prototype DC high voltage generator with the modified multiplier circuits. In this design, the AC low voltage was rectified alternating first, and the DC voltage was multiplied by using the modified multiplier circuit. The circuit output voltages were DC high voltage forms. The DC output high voltages were measured by using a digital storage oscilloscope through a voltage divider. Thus, various DC high voltage waveforms could be measured and recorded by the storage oscilloscope and the data were transferred to the computer.

In this design, it was realized four stages of dc high voltage multiplier, where it was yielded 6185 Volt dc with the input of 600 Volt rms ac, on the no load condition. The average ratio of the dc voltage to rms ac input voltage was 10.76. The average ripple of dc output voltages was 1.134% on the no load condition.

1. BACKGROUND

In the fields of electrical engineering and applied physics, dc high voltages are required for several applications. For example, electron microscopes and x-ray units require high dc voltages, as well as electrostatic precipitators and particle accelerators in nuclear physics. For electrical engineers, the main concern of high high voltages is for the insulation testing of various components in power system. Hence, generation of high voltages in laboratories for testing purposes is essential. Normally, in high voltage testing, the current under conditions of failure is limited to as small value. Generation of high dc voltages is mainly required in research work in the areas of pure and applied physics. Sometimes, high direct voltages are needed in insulation tests on cables and capacitors. Impulse generator charging units also require high dc voltages [1]. There are also various applications of high dc voltages in industries, research medical sciences, etc. HVDC transmission over both overhead lines and underground cables is becoming more popular. HVDC is used for testing cables of lengths as these have very large capacitance. These suffer from the fact that the stress distribution within the insulating material is different from the normal operating condition. In industries, it is being used for electrostatic precipitation of ashing in thermal power plants, electrostatic painting, cement industry, communication systems, etc. It is also being used extensively in physics for particle acceleration and in medical equipment (X-rays) [2]. Generation of high direct voltages are required in the testing of insulation of cables and capacitors where the use of alternating voltages test sets become impractical due to the steady high charging currents [3,4]. In high voltage technology direct voltages are mainly used for pure scientific research work and for testing equipment related to HVDC transmission systems. There still a main application in tests on HVAC power cables of long length, as the large capacitance of those cables would take too large a current if tested with ac voltages. High dc voltages are even more extensively used in applied physics (accelerators, electron microscopy, etc), electromedical equipment (X-rays), industrial applications (precipitation and filtering of exhaust gases in thermal power stations and the cement industry; electrostatic painting and poweder coating, etc), or communication electronics (TV, broadcasting stations).Therefore, the requirements on voltage shape, voltage level, and current rating, short or long term stability for every HVDC generating system may differ strongly from each other. With the knowledge of the fundamental generating principles, it will be possible, however, to select proper circuits for a special application [5,6]. With the widespread development of high voltage dc transmission, test equipment for very high voltages and high currents has gained particular significance in the past few years. The advanced development of high voltage dc power supplies for higher voltages and currents was not only prompted by UHV dc transmission projects, but also by the growing interest of plasma physicist in high-current injectors for experiments on controlled nuclear fusion. It is remarkabel that modern high voltage dc power supplies, like impulse voltage generators, are based on a circuit which has been known for decades [7]. There has been developed dc high voltage generator using Cockcroft-Walton voltage multiplier circuit in laboratory scale and it would be very useful for field testing of HV cables of different voltage grade [8]. Nevertheless, the output voltages, voltage drops and ripple voltages would be better to be measured more accurately. In modern high voltage laboratories and testing installations, semiconductor rectifier stacks are commonly used for producing dc voltages. Semiconductor diodes are not true valves since they have finite but very small conduction in the backward direction. The more commonly preferred diodes for high voltage rectifiers are silicon diodes. For laboratory applications, the current requirement is small and such a selenium element stack may be employed without the use of any voltage grading capacitors. When a full wave rectifier is used along with the smoothing condenser C, the voltage on no load will be the maximum ac voltage. However, when on load, the condenser gets charged from the supply voltage and discharges into load resistance whenever the supply voltage waveform varies from peak value to zero. When loaded, a fluctuation in the output dc voltage δV appears, and is called a ripple. The ripple voltage depends on the supplu voltage frequency, the time constant and the reactance of the supply transformer. The ripple voltage is to kept as low as possible with the proper choice of the filter condenser and the transformer reactance for a given load [1]. This case not only function of diodes, but also capacitors. The capacitors contribute to generate the high voltage pulses [9]. The capacitors could also make the voltage multiplier [10-17]. Cascaded voltage multiplier circuits for higher voltages are cumbersome and require too many supply and isolating transformers. It is possible to generate very high dc voltages from single supply transformers by extending the simple voltage doubler circuits. This is simple and compact when the load current requirement is less than one milliampere, such as for cathode ray tubes, etc. On the no load condition, the high voltage output will reach maximum voltage of [5]

$$V_{out\,max} = 2nV_{max} \quad \text{. . . . . } (1)$$

While, the value of a direct voltage is defined by its arithematic mean value Vd and is expressed mathematically as [2]

$$V_d = \frac{1}{T}\int_0^T v(t)\,dt \quad \text{. . . . . } (2)$$

The generations of high voltage are divided into several types, such as the generation of high voltage alternating current (AC), high voltage direct current (DC), high voltage ligthning impulse, high voltage voltage high frequency and high voltage switching impulse. The generation of high voltage direct current (DC) can basically be done in several ways. Nevertheless, the basic method that we have designed the DC voltage generation was the generation of high voltage direct current with the modified Cockroft-Walton circuit.

The generation of high voltage direct current aimed to discover the phenomenon of high voltage electricity such as in insulators. Therefore, in making this report, we created a tool that intended as a test source of high voltage insulation materials, and then possible to be developed to a higher voltage class. The high voltage will gradually degraded insulation system blindly as applied on the electrical equipment. The specific objectives to be obtained in this research was the prototype design of miniature high voltage direct current generator utilizing the modified Cockroft-Walton multiplier circuit.

Some urgencies of the research were carried out as follows.

1. The direct current voltage generator was one of the most important equipment, in particular for the laboratory scale, for the purposes of research and testing of various phenomena of high voltage electrical insulation materials, which are solid, liquid or gas insulation.
2. The targeted innovation was use high voltage direct current generation utilizing a modification in line with the Cockroft-Walton multiplier circuit.
3. Realizing the dc high voltage generator by changing the direction of this great range of amplitude, ie by adjusting the value of alternating current voltage input.
4. Simulating and measuring the dc high voltage output signals more accurately using a storage digital oscilloscope.
5. The prototype was very useful as a basis for the larger scale design of high voltage impulse generator source. The impulse voltage generator will be useful for research and testing of various insulation materials on electrical system.

2. RESEARCH METHODS

Basically, the block diagram of the design of high voltage direct current generation, including measuring and loading systems is shown in Figure 1. From the regulated a.c. single phase supply, 0-220 Volt, 50 Hz, the electric source feeded the low voltage insolating transformer. The function of the transformer was isolating between the source circuit and the main rectifier and cascade multiplier circuits. Besides that, it was also as a.c. voltage step up transformer, although it was still in a low voltage range. From the transformer secondary side, the electric source feeded to the full wave rectifier. Therefore, it was yielded a d.c. voltage quantity. This d.c. voltage was magnified by using the modified Cockroft-Walton cascade multiplier up to four stages. Thus, it was resulted d.c. high voltages. These voltages were measured and recorded by using a precise digital storage oscilloscope through a voltage divider circuit on no loaded and loaded conditions.

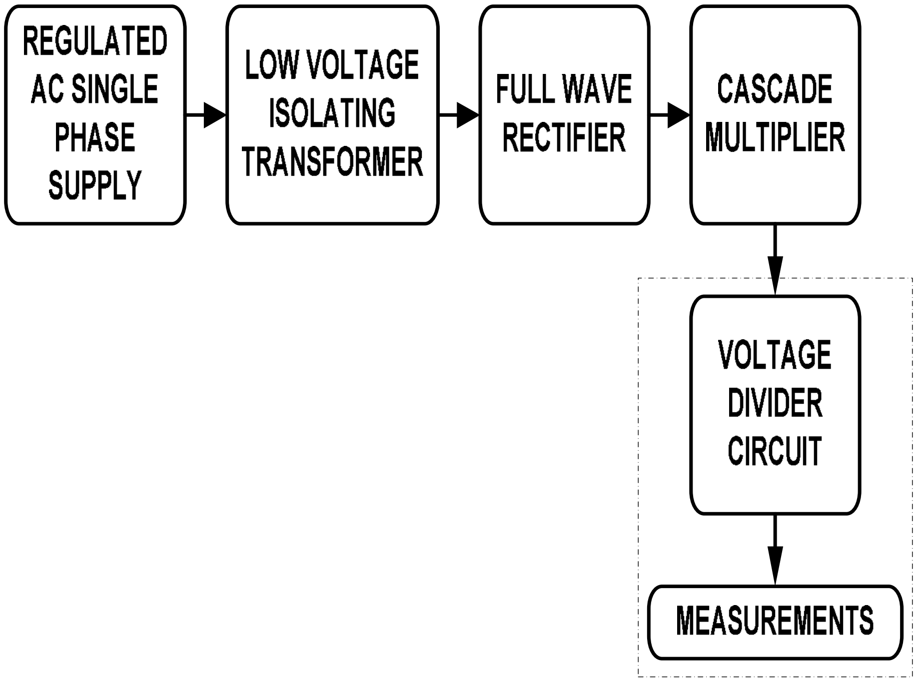


Figure 1. Diagram block of designed d.c. high voltage generation circuit

After making the concept of the d.c. high voltage generation, including the measuring circuit, it was necessary to make the simulating circuit. This simulation was for second preliminary design before making real design or implementation of the circuit. This simulation was also for making sure and safe conditions in the hardware implementation. There was a modification, that was the capacitors were in series, four and three capacitors in one series, to minimize the voltage stresses in each capacitor. Actually, there have been made one up to four stages of simulating circuits, including the simulating results. Nevertheless, it is shown the four stage of simulating circuit only, in Figure 2. In the simulation, it was used PSIM software. It is shown that the first part of circuits was isolating transformer, which received the electric source and forward to the first stage of the cascade multiplier circuit, which was rectified by the diodes. After that, it was multiplied up to four stages. The output voltage was measured by using voltmeter, as the real simulating output voltage. Nevertheless, it was necessary to use a voltage divider using some resistors, which decrease the real high voltage to the low voltage, as representation of the real voltage, and read by a low voltage voltmeter. This low voltage was really to recorded by the storage digital oscilloscope in the implementing hardware circuit.

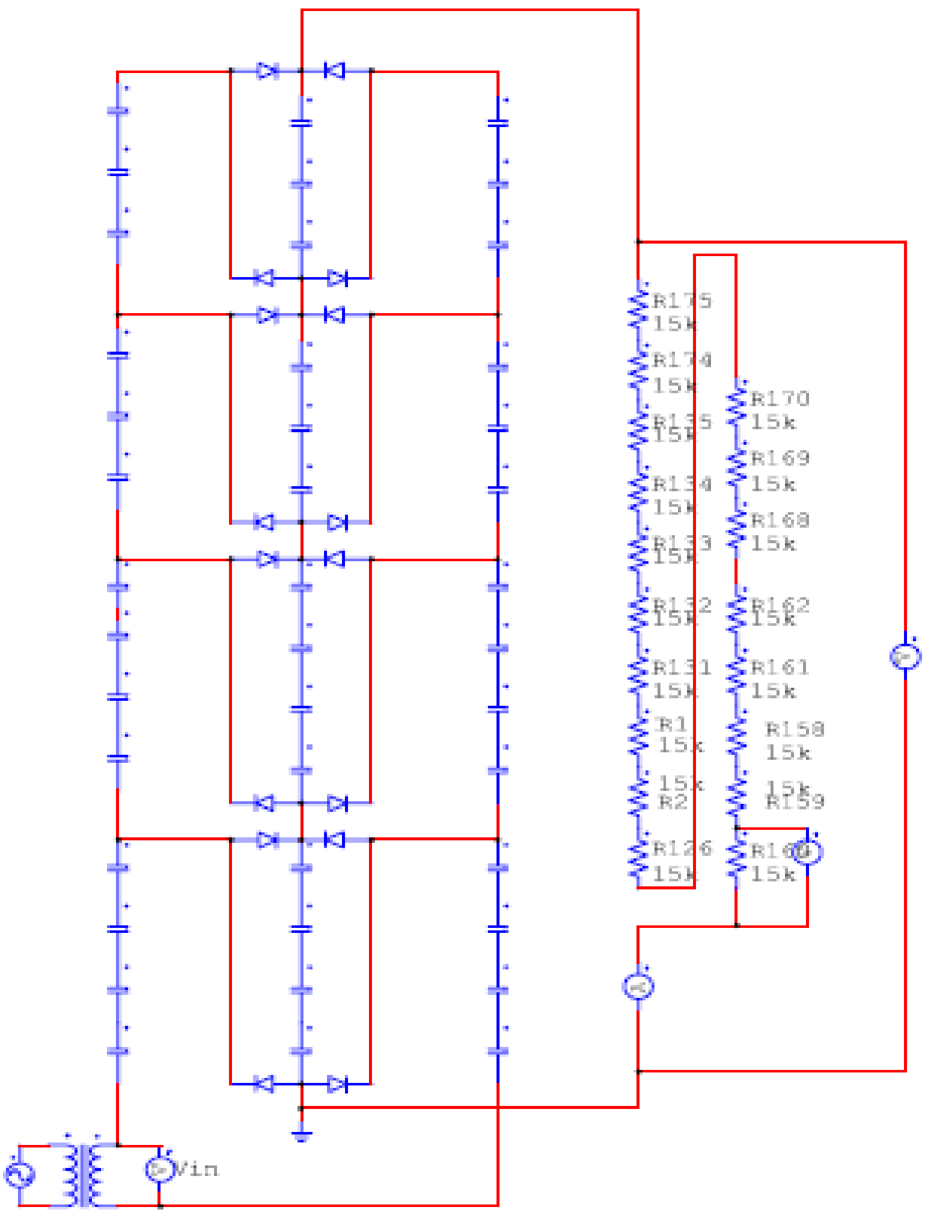


Figure 2. Simulation circuit of four stages of d.c. high voltage cascade multiplier

After making the simulation, it was necessary to the make assembly of required components. In assembling in the generation of high voltage direct current circuit, the necessary main components were transformer, diodes, capacitors, resistors, circuit breaker, fuse, connecting wires, printed circuitd boards, and fixing and casing equipment.

The used transformer was low voltage isolating step-up transformer, where the characteristics was 500 Watt, 0.5 Ampere, 220V input voltage and 110V, 220V, 630V and 1000V output voltage tappings, as shown in Figure 3. The transformer serves as the main separator circuit electrically between the source and the rectifier and voltage multiplier. Thus, the circuit will be relatively safe, which when occurring of typical short circuit, it does not directly influence the voltage source, and vice versa. In addition, this transformer function was for slightly voltage step-up, as above values.

(a) side view **(b) top view**

Figure 3. Isolation step-up transformer supply to the rectifier

In the assembling of high voltage direct current generation, the diodes were the important role. The working principle of the diodes is only one issue with the flow, either positive or negative depending on the purpose of the output. In this diode assembly, it was used high-voltage diodes, as type 25F120 / 1322. Beside the diodes, the capacitors had also the important role, for charging and discharging the electric charges. The capacitors those used to design in this circuit were PAG/450 Volt-100μF types. Figure 4 shows a part of d.c. high voltage generation, that consisted of the capacitors and diodes for rectifier circuit and cascade d.c. voltage multiplier.

(a) Top view **(b) Side view**

Figure 4. The rectifier and multiplier circuits consist of capacitors and diodes

The transformer and the rectifier and multiplier circuits should be connected properly. Figure 5 shows the transformer that would be connected to the rectifier. This connection was also equipped by protective devices, namely a miniature circuit breaker (mcb) and fuse, for safety purpose. The miniature circuit breaker, in this circuit served as a backup protection and safety switch, with the characteristics 6 ampere class. On the other hand, the fuse served as main protection of the circuit with the maximum characteristics of 2.0 ampere. The connecting wires, in this assembly, were almost NYA 1000 Volt type.

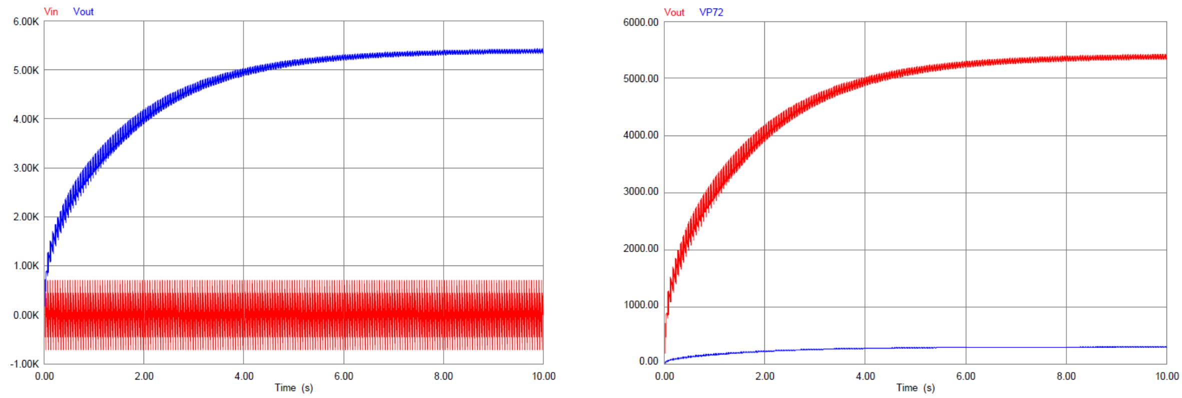
Figure 5. The transformer would be connected to the rectifier and voltage multiplier circuits

The resistors were used as the voltage divider and loads. These components were connected in series and parallel, depend upon the necessary circuits. These resistors were majority of ceramics. The high voltage side of voltage divider was connected to the output d.c. high voltage. On the other hand, the low voltage side of the voltage divider was connected to the storage digital oscilloscope, for measuring and recording purpose. Finally, the recorded data were transfered to the computer. The softfiles in the computer could be as both bmp and csv files, which were for the further observation and computer (laptop) for recording and saving measured data. Figure 6 shows the storage digital oscilloscope and computer for recording and saving measured data of d.c. high voltage.

Figure 6. Storage digital oscilloscope and computer for recording and saving measured data

3. RESULTS AND DISCUSSION

For preliminary study, the progress results have been presented or disseminated on the national conference [18]. Nevertheless, it was only in three stages and no load condition. Hence, the research was further continued, with higher stage and deep analysis. Figure 7 shows the simulation results of the four stage d.c. voltage cascade multiplier. Figure 7(a) shows the output d.c. high voltage and the input a.c. voltage. The output d.c. high voltage would increase and be steady to a certain values, although the input a.c. voltage was remained constant. Actually, the output d.c. high voltage depended upon the input a.c. voltage amplitudes, the number of cascade multipliers and the components, especially the capacitors. Figure 7(b) shows the output d.c. high voltage and the output d.c. low voltage on the voltage divider. Although both quantities were not same, their quantities were proportional. The output d.c. low voltage was the quantity that measured by the d.c. voltmeter and the oscilloscope on the real condition.



(a) Output d.c. and input a.c. voltages **(b)** Output d.c. and low side divider voltages

Figure 7. Output voltage of simulation results

Figure 8 shows the complete circuit of implemented miniature d.c. high voltage generator. There were 4 (four) stages of d.c. multiplier, where each stage consisted of capacitors and diodes. It is also shown the voltage divider, on the right side, for measuring purposes.

Figure 8. Complete circuit of implemented miniature d.c. high voltage generator

International Journal of Electrical Engineering and Technology (IJEET), ISSN 0976 – 6545(Print), ISSN 0976 – 6553(Online) Volume 6, Issue 1, January (2015), pp. 01- 12© IAEME

Figure 9 shows the complete circuit of implemented miniature d.c. high voltage generator and measuring equipment. The storage digital oscilloscope was used to measure and record the output d.c. high voltage through the voltage divider. The recorded data could be saved in both bitmap (bmp) and comma-separated values (CSV) soft files. These data were transferred to the computer (laptop) The bmp files were usually for further observation or comparison purposes, especially the wave forms and magnitudes. On the other hand, the csv files were for further analysis using Excel software. The analyses were the real magnitude and form of the output d.c. high voltages, voltage drops and voltage ripples. The magnitude values of real high voltage were the read and recorded values on the d.c. voltmeter and the oscilloscope multiplied by the ratio of voltage divider and/or the differential probe. For safety purpose in the recording, it was installed the differential probe and surge arrester for the oscilloscope probe. Thus, the oscilloscope would be safer.

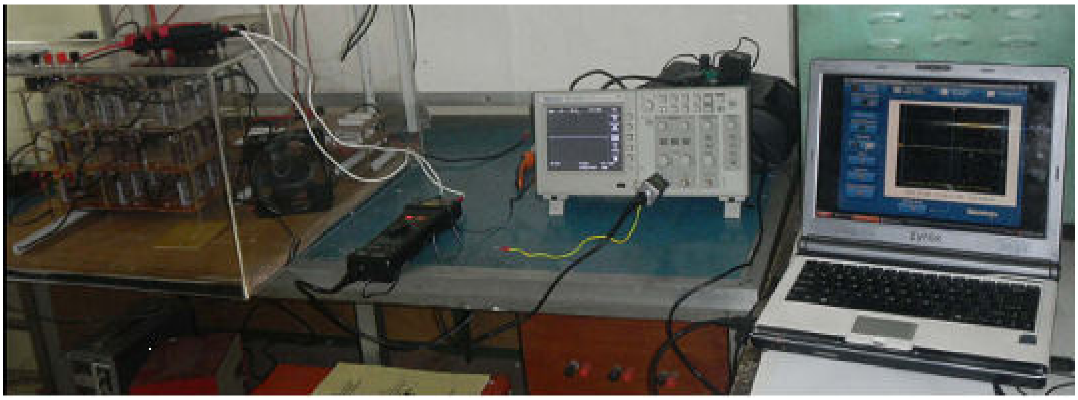
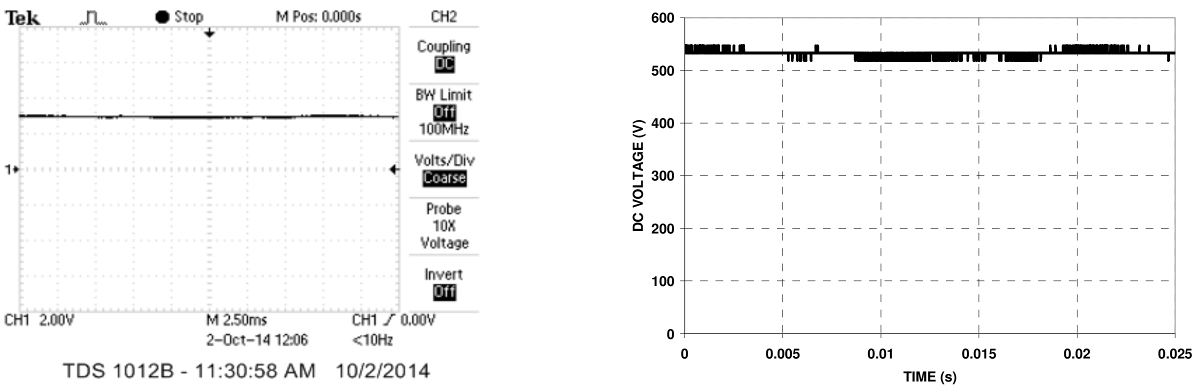


Figure 9. Complete circuit of implemented miniature d.c. high voltage generator and measuring equipment

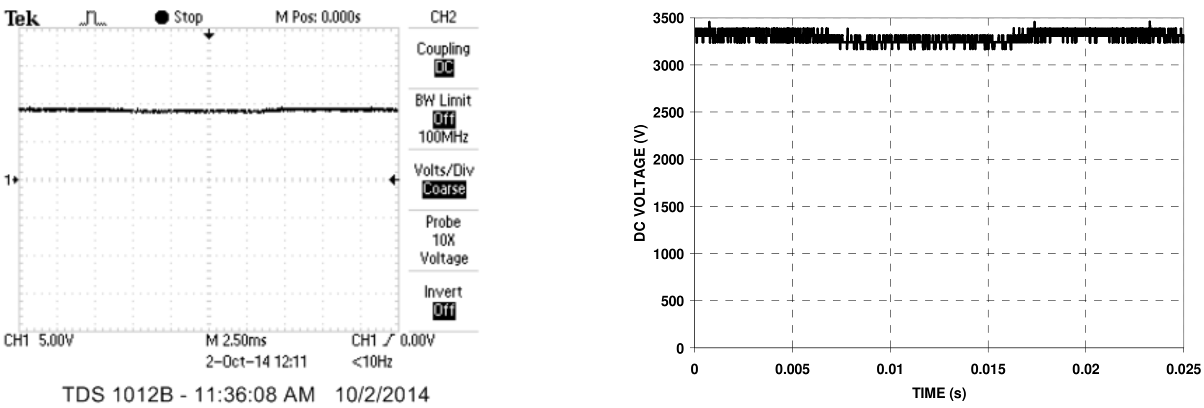
Figure 10 upto Figure 12 show the samples of generated DC high voltages as function of time. These voltages were on no load condition, although only the voltage divider was installed over the high voltages. Figure 10 shows the generated DC high voltages as function of the AC input voltages. In this measurement, the input a.c. that read by a.c. voltmeter was 50 Volt rms. This voltage yielded the average d.c. output voltage of 532 Volt. Figure 10(a) shows the recorded bitmap data of the measurement, while Figure 10(b) shows corresponding data of d.c. output voltage after multiplied by the ratio of voltage divider and/or differential probe.



(a) **(b)**

Figure 10. Generated d.c. output voltage on the input 50 VAC

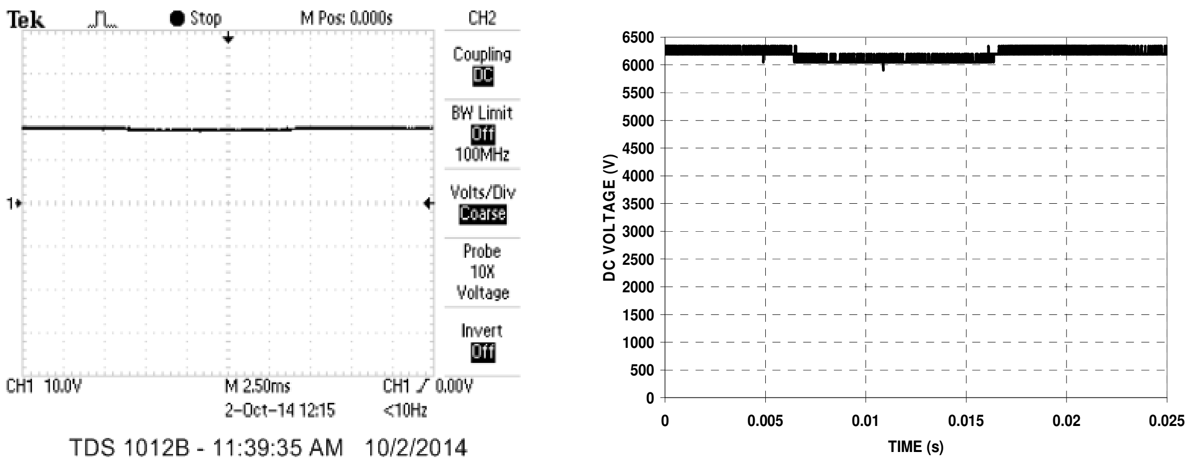
Figure 11 shows the generated DC high voltages as function of the AC input voltages, where the input a.c. that read by a.c. voltmeter was 300 Volt rms. This voltage yielded the average d.c. output voltage of 3292.7 Volt. Figure 11(a) shows the recorded bitmap data of the measurement, while Figure 11(b) shows corresponding data of d.c. output voltage after multiplied by the ratio of voltage divider and/or differential probe.



(a) **(b)**

Figure 11. Generated DC output voltage on the input 300 VAC

Figure 12 shows the generated DC high voltages as function of the AC input voltages, where the input a.c. that read by a.c. voltmeter was 600 Volt rms. This voltage yielded the average d.c. output voltage of 6184.8 Volt. Figure 11(a) shows the recorded bitmap data of the measurement, while Figure 11(b) shows corresponding data of d.c. output voltage after multiplied by the ratio of voltage divider and/or differential probe.



(a) **(b)**

Figure 12. Generated DC output voltage on the input 600 VAC

Figure 13 shows the curve of output d.c. high voltage versus input rms ac voltage measured data. The output voltage measured data consisted of two measuring results, namely rms d.c. voltage and average d.c. voltage. The former was the measuring results using d.c. voltmeter, and the latter was the recording data using the oscilloscope. Both quantities were linearly proportional to the rms a.c. input voltage. There was small deviation between both quantities. Nevertheless, it was still fair. Based on these data, the average ratio of the dc voltage to rms ac input voltage was 10.76 and the average ripple of dc output voltages was 1.134%. In this case, the average ripple of d.c. output voltage was defined as the average of deviation to the real value was delivered by the average values of d.c. output voltage values.

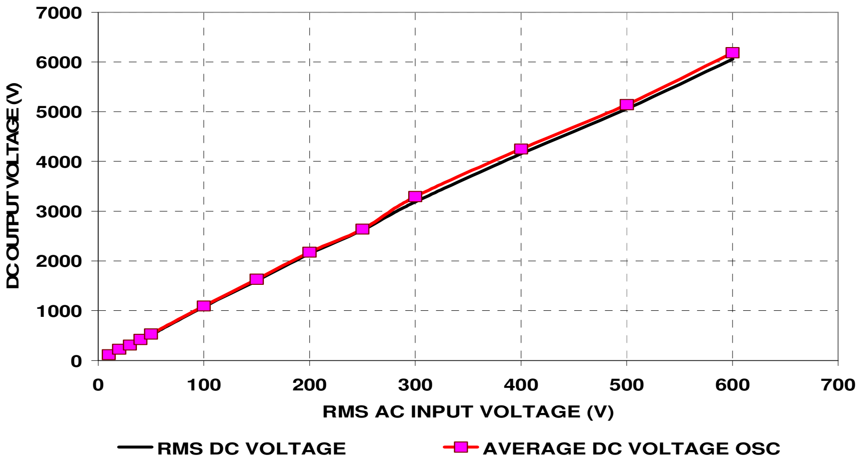


Figure 13. Output d.c. high voltage versus input rms a.c. voltage

4. CONCLUSIONS

For a while it can be concluded that the direct voltage can be raised or folded into a higher voltage, low voltage, below 1000 volts, into a medium voltage above 1000 volts, both in simulations and in real terms in a series of hardware that has been assembled. In the simulations and hardware designs, it was designed to 4 (four) level so that the output voltage can reach approximately 6185 Volt DC. The values of d.c. output voltage were precisely linear to the rms a.c. input voltages. On the no load conditions, the d.c. output voltage was quite small, as 1.134%.

ACKNOWLEDGMENTS

We would like to express the deepest appreciation to The Institute for Research and Community Service, National Institute of Technology (ITENAS), which has supported the funding in the research.

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This is to certify that Mr/Ms/Mrs. **WALUYO** has published research paper in International Journal of Electrical Engineering and Technology (IJEET), Volume 6, Issue 1, January (2015), pp. 01-12.

Paper Title: "**MINIATURE PROTOTYPE DESIGN AND IMPLEMENTATION OF MODIFIED MULTIPLIER CIRCUIT DC HIGH VOLTAGE GENERATOR**".

Co-Authors: Mr/Ms/Mrs. **SYAHRIAL, SIGIT NUGRAHA, YUDHI PERMANA JR**

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