INTRODUCTION

Voltage multiplier circuit: It is already known how a transformer functions to increase or decrease voltages. It is also known that a transformer's secondary may provide one or more A.C. voltage output which may be greater or lesser than input voltage. When voltages are stepped up current decreases and when voltages are stepped down current increases. There is another method to increase voltage that is voltage multiplier. Voltage multiplier circuits are used primarily to develop high voltages where low current is required. The output voltage of Voltage multiplier circuits may be several times more than the input voltage. For this reason, Voltage multipliers are used in special applications where load is constant and has high impedance or where input voltage stability is not critical. The classification of voltage multiplier depends on the ratio of output voltage to input voltage such as doubler, tripler, quadruples and n-plex.

The Voltage multiplier circuit which has the ratio of output voltage to input voltage depending on number of stages is called Cockcroft-Walton Voltage multiplier circuit which is used to develop high voltages in order of several kV. An output voltage, from any stage, can be taken out through tapings. In this work, the input voltage, for Cockcroft-Walton voltage multiplier, has been taken from the secondary of single phase step-up transformer to minimize hazards whereas primary feeds control circuit. In this way Cockcroft-Walton voltage multiplier is isolated from main line as result mitigation of switching surge voltages.

In this project, the main emphasis has been given on the first stage on design, simulation and development of high voltage D.C. power supply. During the second stage, the D.C. power supply is constructed based on hardware implementation which can be utilized for various applications. The first stage of this work focuses on studying voltage doubler circuits and Cockcroft-Walton voltage multiplier circuits and to simulate the circuit for designated value of D.C. output voltage. And finally, prototype hardware (assembly of components) is constructed in laboratory at the output D.C. Voltage of 60kV based on Cockcroft-Walton voltage multiplier circuits. The conventional technique is used because the designed set is intended to be applied for VLIF, OWTS, and Impulse charging units or laser excitation. The main components, used for construction of high voltage D.C power supply, are epoxy molded single phase step-up transformer, diodes and capacitors. The control systems are on low voltage side (that is, 220 volts) considering the safety factors for operator. The different voltage can be taken out through tapping at every stage of C.W voltage multiplier circuit. This test set will be friendly user in industries for field testing as well as in laboratory. The advantages of this set are low cost, high reliability, portability and simple control.

COCKCROFT-WALTON VOLTAGE MULTIPLIER CIRCUIT

In 1932 Cockcroft-Walton suggested an improvement over the circuit developed by Greinacher for generation of high D.C. voltage. Figure 1 shows multi stage single phase circuit of Cockcroft-Walton type.

In Figure 1, the portion, ABM'MA exactly identical to voltage doubler circuit. During the next half cycle when B becomes positive with respect to A, potential of M falls and therefore, potential of N also becoming less than potential at M’, hence C2 charged through D2. Finally all the capacitors C1, C2’, C3, C1, C2 and C3 are charged. The voltage across the column of capacitors consisting of C1, C2, and C3 keeps on oscillating as supply voltage alternates. Therefore, this column is known as oscillating column. However, the voltage across C’1, C’2, C’3, remains constants and it is known as smoothening column. The voltage at M’, N’ and O’ are 2, 4 and 6Vmax. Therefore voltage across all the capacitors is 2Vmax, except for C1 where it is Vmax only. The total output voltage will be 2nVmax where n is the number of stages.
Thus the multistage arranged in manner above enables to obtain very high voltage. The equal stress of elements (diodes and capacitors) used is very helpful and promotes a modular design of such generators.

Considering Figure 2, the design of Cockcroft-Walton voltage multiplier circuit is relatively easy. Careful consideration of all component parameters is the only way to insure both reliable and predictable circuit performance. Actually the design of high order cascade voltage multiplier network is not complete, unless the ripple and regulation are not considered. The ripple voltage $\delta V$ and voltage drop $\Delta V$ can be derived in cascade voltage multiplier circuit. The ripple factor $\delta V = (I/f * C) \{n(n+1)/2\}$ where $I =$ load current in amperes, $f =$ frequency in Hz, $C =$ Capacitance in farad, $n1 =$ No. of capacitor $= 2 \times$ No. of stages $= 2n$ ($n =$ No. of stages). So that,

Voltage drop $\Delta V = (I/fc) \{(2/3 \ n^3 + n^2/2 - n/6)\}$

Regulation of voltage $= V/2nEm$,

Ripple (%) $= \delta V/2nEm$

Calculation of optimum no. of stages (optimum) for minimum voltage drop or minimum regulation optimum $= \sqrt{(Em f C/I)}$.
DESIGN CRITERIA

Capacitor selection

The size of capacitors used in multiplier circuit is directly proportional to the frequency of input signal. Capacitor used in off line, 50 Hz application is usually in the range of 1.0 to 200 microfarad. While those used in high frequency applications, say 10 kHz are typically in the range of 0.02 to 0.06 microfarad.

The voltage rating of capacitor is determined by the type of multiplier circuit. The capacitor must be capable of withstanding a maximum voltage depending upon the numbers of staged used. A good thumb rule is to select capacitor whose voltage rating is approximately twice that of actual peak applied voltage. For example a capacitor which will see a peak voltage of 2Em should have a voltage rating of approximately 4Em.

Diode selection

Prior to selection of diode basic device parameter must be considered.

Repetitive peak reverse voltage: Repetitive peak inverse voltage is the maximum instantaneous value of reverse voltage across the diode. Applied reverse voltage below this maximum value will produce only negligible leakage current through the device where as voltage in excess of the maximum value can cause circuit malfunction and even permanent component damage because sufficient leakage current will flow through the device. In case of multiplier circuit reverse voltage seen by each diode is 2Em. So the device must be selected with reverse voltage (VRRM) setting of at least 2Em.

Frequency of input signal: While selecting rectifierdiode, the frequency of input signal to multiplier circuit must be taken into account. For symmetrical input signals, the device chosen must be capable of switching at speed faster than the rise and fall times of the input. If the reverse recovery time is too long the efficiency and regulation of the device will suffer. In the worst case insufficient recovery speed will result in accessing heating of device. And in this case permanent damage of device will take place. The reverse recovery time is very dependent upon the circuit and the condition being used to make the measurement. Reverse recovery Time specification should be used for qualitative, not quantitative purposes since condition specified for the measurement rarely reflects those found in actual real life circuit operation.

Decreasing current flow in the multiplier circuit makes it possible to use higher input frequency. An increase in current flow has been the opposite effect. Ideally the multiplier network load should draw no current.

Peak forward surge current (Ifsm): Peak forward surge current rating is given for most of rectifier diodes. This rating corresponds to the maximum peak value of single half sine wave which, when superimposed on the devices rated load current can be conducted without damaging of rectifier. This rating becomes important when considering the large capacitance associated with multiplier network.

Figure 2 is n-stage voltage multiplier circuit Surge currents can be developed in rectifier circuits due to capacitive loading effects, the large step-up turn ratio between primary and secondary of most high voltage transformer causes the first multiplier capacitor C1(On the secondary side) to be reflected as much larger capacitance in to the primary. There is a thumb rule for calculation of this as follows:

\[ C'1 = NC1, \]

Where C1 = first multiplier circuit capacitance, C'1 = Referred capacitance on primary side N = turns ratio of high voltage transformer N2/N1.

As the circuit turns on, large current will be developed in the primary side as this effective capacitance begins charging. On the secondary side significant surge current can flow through the rectifiers during initial capacitor charging at turn on. The addition of a series resistance Rs can greatly reduced these current surges as well as those in the primary circuitry.

\[ Rs = \frac{V \text{ Peak}}{\text{ Ifsm}}. \]
For example maximum secondary voltage, \( VRMS = 260 \) volts, then \( V_{peak} = 1.414 \times 260 \) V.

\( Rs = 1.414 \times 260 / 15 = 24.4 \) Ohm, \( Ifsm = \) Forward surge current rating of diode = 15 Amp.

**Forward current (I0):** As sited earlier that; ideal multiplier circuit, the load will draw no current. Ideally significant current flow through the rectifier occurs during capacitor charging. Therefore, device with very low current rating (100 mA) and in case of HT/MV cables. It comes to micro amperes can be used. It must be noted that forward current and forward surge current rating are related.

Since both are the function of silicon die area. It is truly speaking that devices with a high surge current rating \( Ifsm \) will also have high forward current \( I0 \) rating and vice-versa.

**Forward voltage (Vf):** In practice the forward voltage drop \( V_f \) of the rectifier does not have significant effect on multiplier networks overall efficiency. For example if the rectifier diodes has forward drop of 2.0 volt when measured at a current of 100 mA. A half wave doublers multiplier with 8kV output will have then 0.05% (2×2/8 kV) loss in efficiency due to forward voltage drop. The above calculation is based on a thumb rule that;

\[
\text{Voltage drop} = \text{No. of stages} \times \text{Forward voltage} \div \text{Output voltage in kV}
\]

**WORK DONE SO FAR**

A prototype of the Cockroft-Walton voltage multiplier circuit consisting of 60 IN4007 diodes and 60 Electrolytic capacitors of rating 2.2uf and 350 V each was made and it was tested on a voltage of 24 V which was obtained by stepping down the normal supply voltage of 220 V by means of a step-down transformer. The output voltage was found to be 3.8 KV

The theoretical output voltage can be calculated from the formula given by –

\[
V (output) = 2*N * Vp
\]

Where \( Vp = \) Peak value of supply voltage.

and \( N = \) Number of capacitors in the circuit.

The theoretical voltage can now be calculated as –

\[
V (output) = 2 * 60 * 33.9 \text{ KV} = 4.072 \text{ KV}
\]

However, as seen above, the theoretical voltage is found to differ from the practical voltage by a fairly large amount. This is due to a “ripple” effect in the voltage which can be expressed in terms of the “ripple voltage“ which can be defined as –

\[
V_r = (I * N * (N+1))/ (2 * C * f)
\] - (1)

Where \( I = \) Load current

and \( C = \) Capacitance

and \( f = \) Driving frequency

This \( V_r \) represents the difference between Theoretical output voltage and Practical output voltage.
A sample of the constructed circuit has been shown below for reference –

**FUTURE ENDEAVOURS –**

As seen above from (1), the ripple voltage turns out to be quite large because the value of N (number of capacitors) is high and their capacitance values \( C \) are low. This large value of ripple voltage isn’t desirable and hence has to be reduced by increasing the capacitance and reducing the number of capacitors. Hence, our future plans include fabricating a new Cockroft-Walton voltage multiplier circuit based on the above findings. Hence, our new parameter values for various circuit components turn out to be as follows –

- Capacitor rating = 1.5KV,
- Diode rating = 1.5KV
- Transformer rating = 220V/1.5KV