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A Novel circuit for DC voltage transformation using transformer

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ABSTRACT

The HVDC transmission is the most efficient mode of the transmission of the electrical power. The most important drawback, which is preventing the widespread use of HVDC transmission, is the inability of DC system to transform the voltages at different levels. This paper proposes the method, which can be used to transform the voltage level in DC network with the use of pure DC signal. The proposed method is based on the fact that the transformer can transform the voltage if the input given to it is continuously varying with respect to time. The pure DC wave is chopped to convert that signal into a square wave that is only positive in magnitude. Then this square wave is applied across RC charging circuit that converts the wave into continuously varying time signal. This signal can then be applied to the transformer, which transforms the signal into required magnitude signal having same wave shape and frequency. However, the signal on the secondary of the transformer is not pure DC but pulsating at certain frequency. The signal is converted into DC with an appropriately designed filter. The concept is validated by developing a prototype model of the proposed method. Thus in DC networks the voltage can be transformed from one voltage level to the other without converter and inverter circuit. Thus proposed method makes DC voltage transformation economical.

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I. INTRODUCTION

Electric power transmission is the bulk movement of electrical energy from a generating station to an electrical load. Electric power transmission was originally developed with direct current. The availability of transformers and the development and improvement of induction motors led to greater appeal and use of AC transmission. Alternating current (AC) became very familiar for the industrial and domestic usage, but still for the long transmission, AC has some limitations including, current and voltage limits, skin effect, switching surges, higher corona, radio interference and excessive reactive power consumption has led to the use of DC transmission [1], [2]. On the other hand, D.C transmission has no reactance problem, no stability problem, and hence no distance limitation [1]. In a HVDC system, electric power is taken from generating station in a three- phase AC, converted to DC in a converter station, transmitted to the receiving station by an overhead line or cable and then converted back to AC in another converter station and injected into the receiving AC network [3],[4]. Since HVDC involves large power electronic devices and transformer at sending as well as receiving end to transfer the generated power from generating station to load side [5],[6]. It leads to

1. High initial cost of power electronic devices used for converting AC power to DC power at required voltage level.
2. Additional losses taking place in power conversion to transmit available AC power in DC form.
3. Needs a separate additional converter station and transformer at each receiving station to stepping down the high voltage to required level.

So the widespread use of the HVDC is limited by the inability of the DC voltage transformation from one voltage level to another voltage level. This is the most important reason for the fallback of the HVDC in the transmission sector. The proposed paper intends to remove this drawback of the system by incorporating a device, which can transform the DC voltage, which will enable the use of DC supply for distribution purpose and hence the losses taking place in distribution network are reduced.

The need of large size power electronic devices (converter – inverting stage) high initial cost associated with it, the maintenance required and the losses in converter stage are eliminated.

The proposed DC transformer in project provides DC voltage along with zero crossing in waveform, which can be used in circuit breaker, and wireless charging [7].

The transformation of the voltage is possible by various means, which are push-pull converter, DC chopper etc. [8],[9],[10],[11],[12]. The Push–Pull converter is a type of DC-to-DC converter, a switching converter that uses a transformer to change the voltage of a DC power supply [9]. The push-pull converter uses the transistors to achieve the transformation action, which proves to be expensive due to presence of the transistors. The push- pull converter is also very complex in operation.

Another mode for transformation of the DC voltage is the DC chopper [10], [12]. The DC chopper consists of the power electronic switch along with the inductor as the energy- storing device. The proper firing of the power electronic device causes the connection of the inductor such that voltage is added up or the voltage is opposed so as to get the required level of the output. The DC chopper requires very high sized inductor for high voltage, which is not practically feasible technically as well as economically. The transformer is the device, which works on the principle of mutual induction [13], [14]. When the continuously varying voltage is applied to the primary of the transformer, the flux is linked with the secondary of the transformer, which induces the voltage in the transformer [15]. This principle can be used with DC if DC is made pulsating by some means. Hence the DC transformer concept was developed. This novel concept of the DC Transformer is validated with the help of a prototype model.

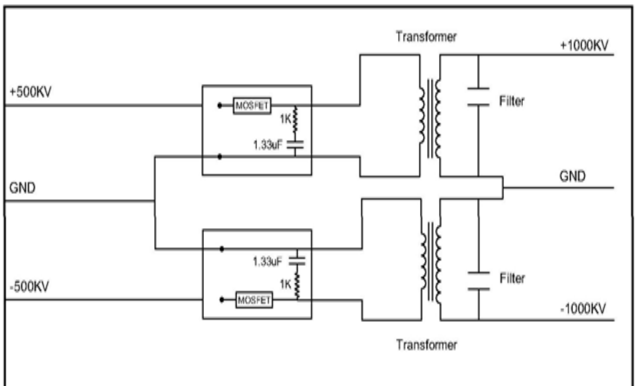


Fig 1. Block Diagram

II. SYSTEM DESCRIPTION AND DESIGN

The project is designed to be used in the bipolar HVDC transmission system. The bipolar HVDC line consist of two poles one positive and other being negative. The same is replicated in the project to describe the use of DC transformer in the HVDC line to enhance the performance and the feasibility of the HVDC system. The block diagram of the proposed project DC transformer in HVDC system is as shown above figure 1. The description of the above block diagram is explained in the following points.

MOSFET and RC charging circuit: - The MOSFET and RC (Resistance and capacitance) charging circuit is used to achieve the signal in the form that is continuously varying with respect to time. The MOSFET acts as a step down chopper and produces the pulses by switching the MOSFET depending on the firing pulses given to MOSFET from arduino microcontroller. The output is obtained in the format as shown below. The duty cycle is adjusted for this MOSFET at 40%. The duty cycle is kept at the value of 40% such that the T_{OFF} period is sufficiently higher to allow full discharge of the capacitor, thereby achieving the waveform as per the requirement.

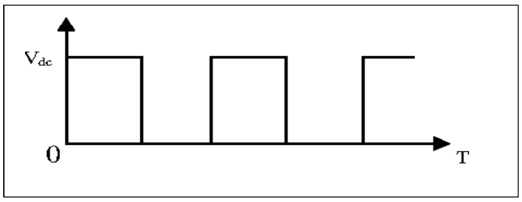


Fig 2 MOSFET output waveform

This output obtained from MOSFET is then given to the RC series circuit which is connected in parallel as shown in below figure 3.

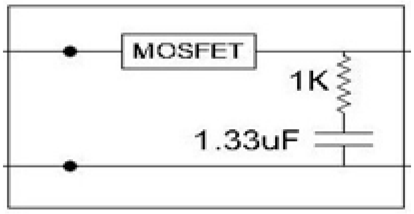


Fig 3 MOSFET and RC charging circuit

The capacitor has property not to allow the sudden change in the voltage across it [6], [7]. Hence it opposes the sudden change in voltage at T_{on} and T_{off} time of the MOSFET, thereby producing the output as shown in figure 4 below.

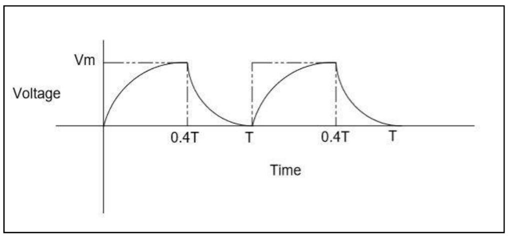


Fig 4 Continuously Varying Time Signal

This voltage which is obtained from the RC charging circuit is continuously varying with respect to time and hence can be applied to the transformer for transformation. This waveform also consists of a zero point which can be exploited for circuit breaker operation [13].

- **Design of wave shaping parameters:-**

The wave obtained exponentially increases up to 0.4T and the exponentially decreases up to T, where T is the time period. To achieve this the values for resistance (R) and capacitance (C) are calculated as below [8],[9]:-

T=0.02 sec

$\rightarrow 0.4T = 0.4\times0.02 = 0.008$

Ton = 0.008

For RC series circuit,
Ʈ= R×C

Let R = 1000Ω

Ʈ= 1000×C

But Vc reaches to maximum value in 6 Ʈ

6 Ʈ= 1000×C

C= 1.33μF.

- **Waveform Synthesis:-**
  The average value of the signal can be calculated by following generalized formula (1).

$$V = \frac{1}{T}\int_0^t V dt \quad ....(1)$$

Similarly the RMS value (2) can be calculated by

$$V_{RMS} = \frac{1}{T}\int_0^T V^2\, dt \quad ...(2)$$

The obtained values of the average and RMS voltage for this waveform are

$V_{AVG} = 0.3338\ V_M$

And

$V_{RMS} = 0.548\ V_M$

Hence the form factor for this capacitor charging and discharging waveform is

$$\text{Form Factor} = \frac{0.548Vm}{0.33Vm} = 1.66$$

$$\text{Average rate of change of voltage} = \frac{magnitude}{time}$$

$$= \frac{\left(1/_{0.008} + 1/_{0.012}\right)}{2/_{0.02}}$$

$= 2.08$

As shown in the fig. 5 flux increases from zero value to maximum value Φm in $\frac{1}{2.08} f$

Therefore, Average rate of change of flux

$$= \frac{\Phi m}{1/_{2.08} \times f}$$

$$= 2.08 \times f \times \Phi m \times T$$

$$= 2.08 \times 1.66 \times f\Phi m \times T$$

$E_{RMS} = 3.41\ \Phi m\ f\ T$

Now the de rating of the transformer is obtained by comparing above voltage equation with standard equation.

$$= \frac{3.41\times\Phi m\times f\times T}{4.44\times\Phi m\times f\times T}$$

$= 0.768$

Degree of degradation $= 1 - 0.768$

$= 0.232$

Hence the de rating of the transformer is by 23.2%.

- **Filter Design:** - The smoothening capacitor is used filter out the ripple which are present in the output of the transformer [2], [6]. Hence the capacitor smoothens the output thereby reducing harmonic content in the DC output which is obtained from the project.

Design: -

Q=C*V .... (3)

Q=I*T ..... (4)

T=1/F

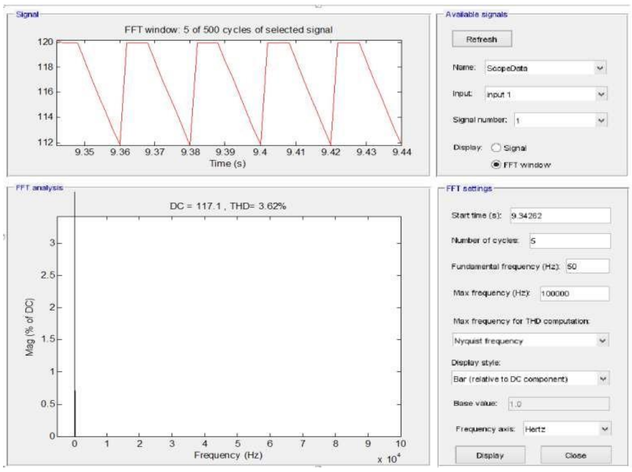
T = 1/50 = 0.02 sec

Equating Equation (3) and (4)
C*V = I*T

∴ C= I*T/ΔV … (ΔV = Peak to peak ripple)
∴ C= 1*0.02/115 …. (I=1A)
(ΔV =115--- Assumption)

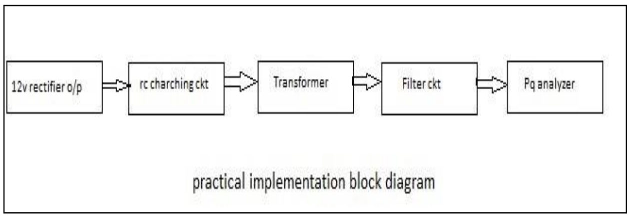
C= 173.91μF

Hence the THD with filter in place is simulated using MATLAB and found out to be 3.62%.



III. EXPERIMENTAL WORK AND RESULTS

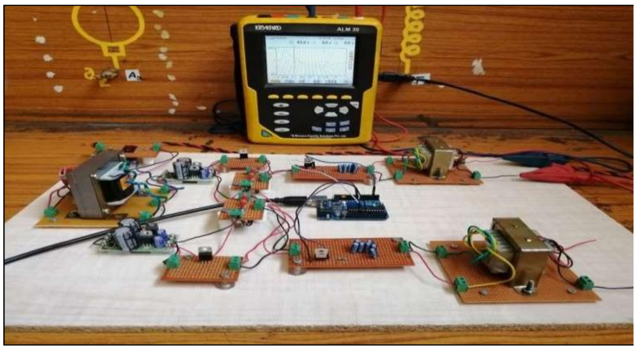
The circuit similar to the one shown in the block diagram (fig 1) is constructed and it was tested for the voltage of 6.45V and 8V RMS. The voltage was applied on the input side and the output voltage was obtained about 85V RMS for 6.45V input and 138V RMS was obtained for 8V RMS at input. The following is the description of the same.

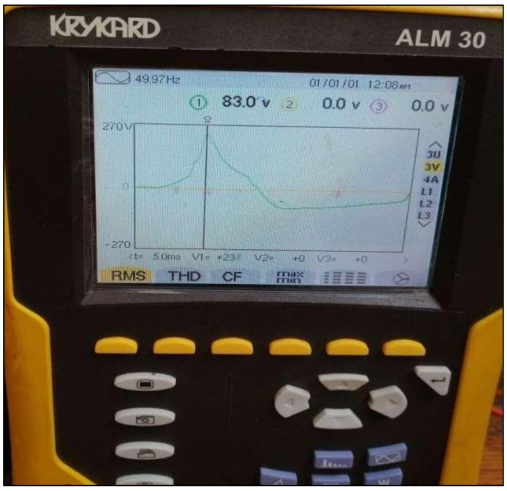


practical implementation block diagram

Referring above figure, initially the ac signal is converted into dc signal of 12V (peak). Then this 12V DC signal is chopped at certain frequency with the help of MOSFET. Then it is applied to RC charging circuit to form a continuously varying signal with respect to time. Finally, this continuously varying signal with respect to time is given to transformer. Hence the transformer action is achieved. The amplified signal from transformer secondary is pulsating in nature, hence in order to obtain pure dc signal filter circuit is used. The output is measured on power quality analyzer and digital signal oscilloscope.

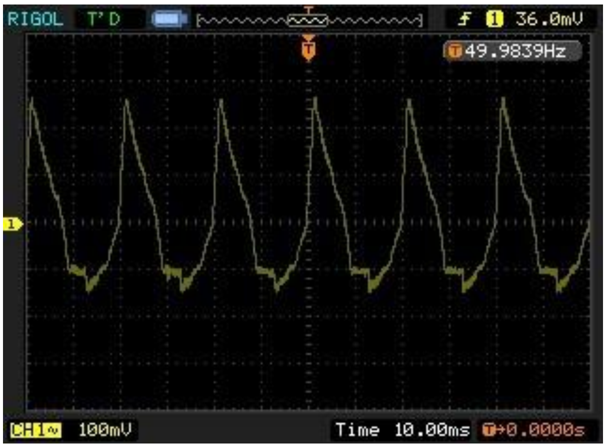
Results:-


The prototype model along with power quality analyzer



Power Quality analyzer window for 4.5V at input

Power Quality analyzer window for 8V at input



Waveform observed on DSO

IV. CONCLUSION

Thus, the proposed novel idea of the DC transformer is having high potential to overcome the inability of voltage transformation. The DC transformer concept is validated using a prototype model. The proposed DC transformer also facilitates the use of circuit breaker in HVDC transmission system. Also the DC transformer facilitates the wireless charging for batteries of electric vehicles as well as batteries in other devices by placing one of the winding of the transformer in electric vehicle and another winding in the

battery charger. The air gap between the windings can be kept minimum to achieve the high efficient charging of the battery. This which will encourage the use of electric vehicles in near future leading to the clean transport.
The proposed DC transformer can be used as a low cost alternative to back to back converter inverter station with higher efficiency with the proposed DC transformer.
The changes in the assumptions and the design formulae are required while designing the transformer for DC signals. The signal which can be applied to transformer is unidirectional in nature and hence requires higher core size. This increase in core area can be compensated by increasing the frequency of the signal.
The proposed DC transformer uses circuitry that converts the DC signal into the continuously varying time signal which consist of the zero point. This zero point can be exploited for the circuit breaker operation as at this zero point the current is zero hence the possibility for breaking circuit without formation of the arc is high. Hence this DC transformer also facilitates the circuit breaker operation in high voltage DC transmission.
Thus the proposed DC transformer reduces the cost of the voltage transformation in DC hence encourages the use of renewable energy such as solar energy.

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