International Conference on Innovative Applications of Computational Intelligence on Power, Energy and Controls with their Impact on Humanity (CIPECH14) 28 & 29 November 2014

Comparisons Among Different Types of Single Phase Step Down AC to DC Converters

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***Abstract*— This paper represents comparisons between different types of AC to DC step down converters. Equations of output voltages for different methods are derived depending on the equations of the circuits. Parameters of the equations for different converters are analyzed to identify the operational flexibility. Merits and demerits of the converters are also highlighted in this paper. Simulations of the converters are performed using MATLAB/SIMULINK and PSIM.**

Keywords— Converter; comparisons; step down; single stage.

I. INTRODUCTION

AC to DC converter is termed as rectifier [1]. The main power supply system is alternating in nature. Rectification action is required to obtain a DC supply from the main power supply which is sinusoidal. In many applications such as battery charging, formation of electromagnet, television, computers and etc requirement of smooth DC signal is obvious. Generally step down action is used to get a lower voltage from the main supply system [2]. Ripple in current and voltage waveforms is reduced by using a low pass filter [2], [3], [4]. Different techniques are used to get the desired form of stepped down DC signal from the main power system.

One of the methods uses transformer to step down the AC voltage and rectifier to get unidirectional signal [5]. Another method uses rectifier and DC chopper to get stepped down DC voltage [5], [6]. Controlled rectifier uses SCR which is operated using gate pulses at different delay angle. Several research works on single stage direct ac to dc step up and down conversion has been done [5]. Size is always an important issue of consideration for designing a converter [7]. One research on single stage AC to DC direct stage step down conversion is analyzed in this paper to compare with other methods.

Mathematical equations and operations of different converters are analyzed in section II. Flexibility of operation of different converters is investigated based on the numbers of stages and parameters of mathematical equations in section III. Simulation is performed using MATLAB/SIMULINK and PSIM in section III.

II. ANALYSIS OF THE OPERATION OF DIFFERENT STEP DOWN AC TO DC CONVERTERS

One of the traditional methods uses transformer and rectifier to get stepped down DC voltage from main AC supply. Fig. 1 shows the method. Transformer is used to step down the AC supply voltage and rectifier is used to get the DC voltage. A filter is used to get smooth DC voltage.

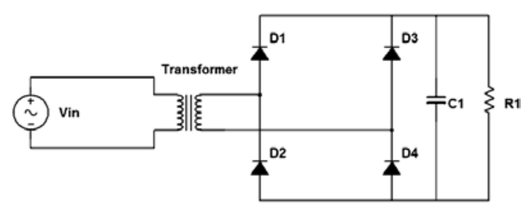

Fig. 1. Use of transformer and rectifier to get a stepped down DC voltage from main AC supply

In this case there are two stages which reduce the efficiency due to power losses in two stages. Transformer has core loss which is divided into two types. One of the transformer losses is termed as eddy current loss and another one is hysteresis loss. In the rectifier the losses take place in diodes. The size of the transformer is large. Due to existence of two stages the size of the whole converter is large. The output voltage across *R1* for this case can be expressed as,

$$Vo = \frac{2*V\sec(p)}{\pi} \tag{1}$$

Vsec(p) is the peak value of secondary voltage of the transformer.

$$n = \frac{V\sec(p)}{Vpri(p)} \tag{2}$$

n is the ratio of primary voltage to secondary voltage of the transformer. For a step down transformer the value of *n* is less than one. *Vpri(p)* represents the peak value of the primary voltage of the transformer or main AC supply. Combining (1) and (2),

$$Vo = \frac{2 * n * Vpri(p)}{\pi} \quad (3)$$

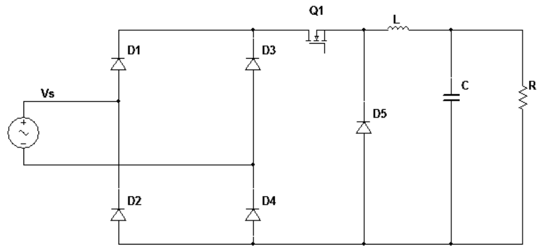

Fig. 2. Use of rectifier and DC chopper to get a stepped down DC voltage from main AC supply

In this method two power electronic converters are added to get rectified stepped down voltage. Fig. 2 shows the process. A rectifier circuit provides unidirectional voltage from AC main supply. DC chopper is used to get a lower valued DC voltage. Switching of the DC converter is controlled to vary the level of DC voltage. In this scheme there is no transformer so the size will be smaller than the previous method shown in Fig.1. The presence of two stages will be a reason of power losses of the converter. The average value of output voltage of single phase full wave bridge rectifier is,

$$Vo(rect) = \frac{2 * Vin(p)}{\pi} \quad (4)$$

Vin(p) is the peak value of voltage of AC main supply. The output of step down DC chopper is,

$$Vo(chopper) = D * Vin \quad (5)$$

Vo(chopper) is the output of the DC chopper, *D* is the duty cycle defined as the ratio of the pulse width of the switching square wave to switching period and *Vin* is the input to the DC chopper. From Fig.2 it is seen that, the output of the rectifier acts as an input to the DC chopper. Combining (4) and (5),

$$Vo = \frac{2 * D * Vin(p)}{\pi} \quad (6)$$

Previous methods are based on two stages which increase the power loss and size as well. This two desired action can be performed using single stage converter.

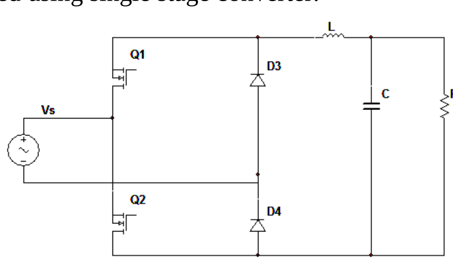

Fig. 3. A single stage stepped down rectification system

In this case the diodes contribute in rectification and the switches control the value of output voltage. Using different tricks in pulse width modulation of switching the output voltage can be easily set into a desired lower value. The output of this converter can be expressed as,

$$V(average) = \frac{2 * Vp}{\pi} * Sin\frac{\pi D}{2N} * \sum_{n=1}^{N} Sin\frac{\pi}{N}(n-1+\frac{D}{2}) \quad (7)$$

V(Average) is the average value of output voltage, *Vp* is the peak value of input sinusoidal wave, *N* is the numbers of pulses in each half cycle of the input sinusoidal wave, *n* is integer and *D* is the duty cycle.

III. Comparisons And Simulation

The outputs of three different converters are expressed in (3),(6), and (7).

From (3) it is seen that for getting desired stepped down DC voltage only the ratio of transformer winding can be changeable. For getting a variable stepped down DC voltage from main AC supply, this scheme will not be that much suitable due to the uneasiness of changing the ratio of numbers of windings.

Equation (6) is for the scheme which contains rectifier and DC chopper. In this case only duty cycle is the variable to change the output voltage of the converter. Varying duty cycle is easier than changing the ratio of transformer winding of the scheme containing transformer and rectifier. So this process is better if compared with the first method. This converter requires a control circuit for pulse width modulation of the switching signal.

From (7) it is seen that the average output voltage is dependent on duty cycle and numbers of pulses. It can be stated that only variable will be the duty cycle to change the output voltage. Though this method and the method containing rectifier and DC chopper depend only on duty cycle, but this process has only one stage which means reduced power losses in the converter if compared with the previous process. Requirement of additional control circuit is obvious in this process.

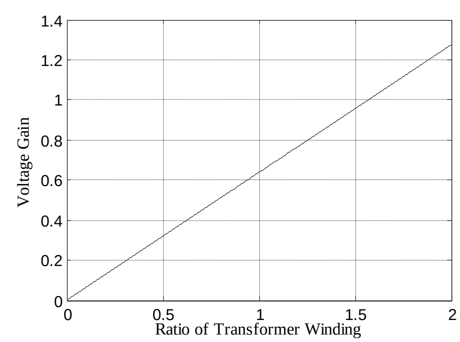

Fig. 4. Voltage gain characteristic of AC to DC step down conversion system using transformer and rectifier

Fig. 4 illustrates the voltage gain characteristic of AC to DC step down conversion system using transformer and rectifier. It is based on (3). The voltage gain of this process is totally dependent on the ratio of transformer winding. It is also clear that step up operation is possible in this method.

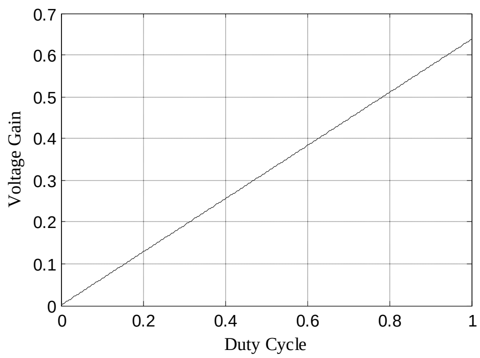

Fig. 5. Voltage gain characteristic of AC to DC step down conversion system using rectifier and buck converter

Fig. 5 illustrates the voltage gain characteristic of AC to DC step down conversion system. It is based on (6). The voltage gain of this process is totally dependent on the duty cycle of switching pulses. Duty cycle will never be greater than one. Step down action is not possible in this process. The maximum voltage gain in this method is 0.6366 or 63.66%.

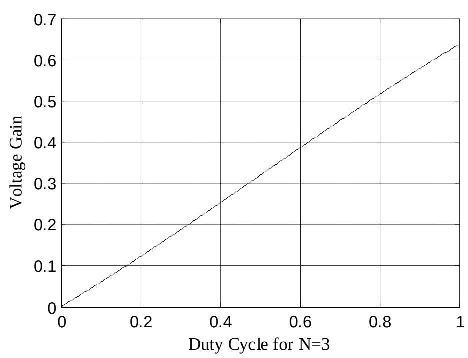

Fig. 6. Voltage gain characteristic of the single stage AC to DC step down conversion process

Fig. 6 shows the voltage gain characteristic of the single stage AC to DC step down conversion process. It is based on (7) and N=3. The voltage gain of this process is dependent on the duty cycle of the switching pulses. Duty cycle will never be greater than one. The maximum gain of this scheme is same as previous scheme but there is only one stage.

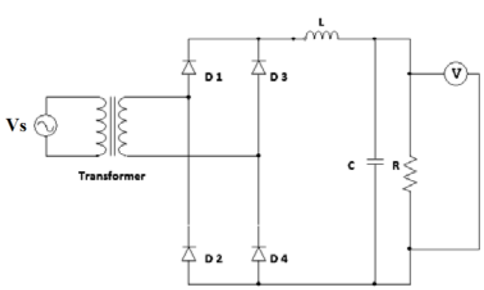

Fig. 7. Simulation of transformer and rectifier method of stepping down and AC to DC conversion process in PSIM

Fig. 7 shows the transformer and rectifier method of stepping down and AC to DC conversion process in PSIM. The transformer steps down the AC voltage and the rectifier rectifies the voltage of secondary. The ratio of numbers of turns of secondary winding to primary winding is 0.606. The peak of input sine wave is 311 V and the output is around 12 V. This calculation is based on (3).

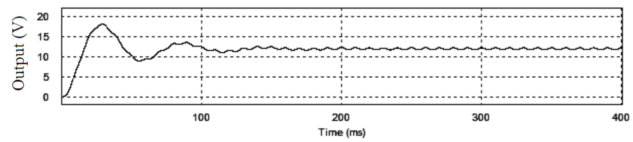

Fig. 8. Output of transformer and rectifier method of stepping down and AC to DC conversion process in PSIM

The output can be only changed depending on the ratio of numbers of turns of secondary winding to primary winding. The output of this method is shown in fig. 8.

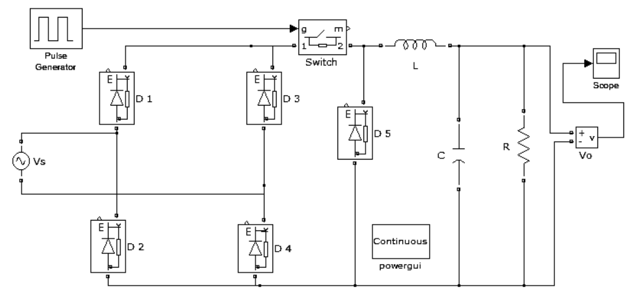

Fig. 9. Simulation of rectifier and buck chopper method of stepping down process in MATLAB/SIMULINK

Fig. 9 shows the circuit of rectifier and buck chopper method of stepping down process. The first stage rectifies and the second stage controls the value of output DC voltage depending upon the duty cycle.

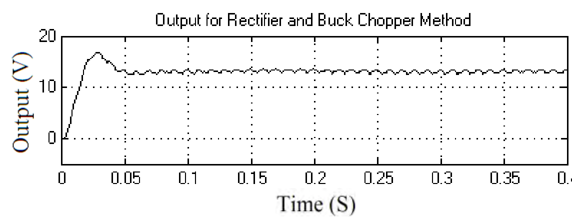

Fig. 10. Output of single stage AC to DC converter

Fig. 10 show the output voltage for fig. 9. This is simulated based on (6). The peak of input voltage is 311 V, duty cycle is 6.06% and output is around 12 V.

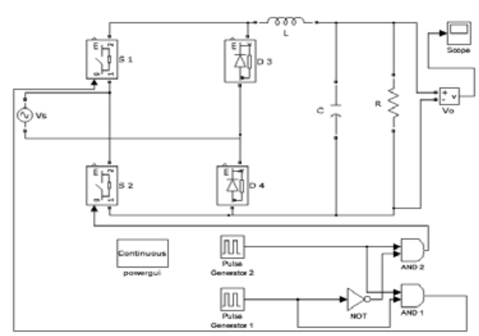

Fig. 11. Simulation of a single stage AC to DC step down converter in MATLAB/SIMULINK

Fig. 11 shows the simulation circuit in MATLAB/SIMULINK for investigating the output of a single stage AC to DC step down converter. It includes a simple control circuit for switching pattern generation. The filter is used to smooth the output voltage.

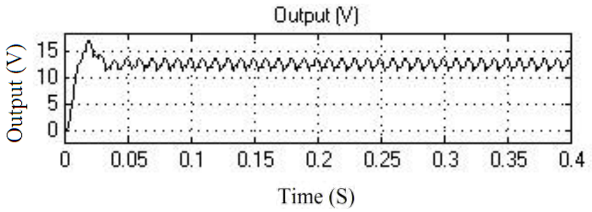

Fig. 12. Output of single stage AC to DC converter

The output is shown in fig. 12. The output voltage can be controlled varying the duty cycle of switching pulses. Input in this case is sinusoidal wave which has a peak value of 311 V and the output for D=6.6% is around 12 V. The output is calculated for N=3 using (7).

TABLE I. COMPARISONS OF THE CONVERTERS

Summary of Comparisons			
	Method I	**Method II**	**Method III**
Circuit	Transformer and rectifier	Rectifier and DC chopper	Modified rectifier with switches
Parameter to change the output	Winding ratio of transformer (n)	Duty cycle (D)	Duty Cycle (D)
Stage	Two	Two	One
Size	Larger	Smaller than Method I	Smaller
Control Circuit	Not required	Required	Required
Flexibility of getting variable DC output voltage	Not flexible	flexible	flexible
Possibility of step up operation	Possible	Not possible	Not possible
Maximum voltage gain	Depends on winding ratio	63.66%	63.66%

Table I represents the summery of the analysis of the converters based on different factors.

IV. CONCLUSION

In this paper three different topologies of step down AC to DC conversions are analyzed in terms of their equations of output voltage. The analysis is based on their numbers of stages, components and control circuits. The demerits of different topologies have been summarized. The characteristics based on the equations are presented to get the idea about the parameters related to the conversion process. It is always desirable to make the size of any converter smaller to increase the efficiency and flexibility of usage.

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