Mousumi Biswal, Sidharth Sabyasachi / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 2, Issue 6, November- December 2012, pp.657-663

A Study on Recent DC-DC Converters

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ABSTRACT

This paper presents a study on recent developments in dc-dc converters. All the converters are derived based on the two basic converters such as buck converter and boost converter. The aims of developing the converters are high efficiency and high gain with fast response. Today's world demands the low power application devices which is the focus of the researchers. There are so many parameters are involved while developing those converters. A lot of computer software has been developed to design such type of converters. With the help of simulations, the behavior of the system can be easily analyzed without any hardware which can prevent the damage. Research work has been grown dramatically to provide the service to the mankind. This paper presents some new converters with suggested control method which can help the researchers to work in that field. MATLAB and PSIM software has been used for simulation.

Keywords–Control Theory, DC-DC Converter, MATLAB, PSIM, Pulse-Width Modulation

"1. Introduction"

The world is now habituated with the electronics devices without which it is very difficult for the mankind to keep going. So it is very important to develop the devices error free and fast response with high efficiency. Of the research field is dc-dc converters. The dc-dc converters mean the input is dc and the output is also dc. The two basic dc-dc converters are buck converter and boost converter. Based on these two converters, all other converters are derived. The semiconductor devices are used as switching devices due to which the converters can operate at high frequencies. The different arrangement of inductors and capacitors in the converters operates as a filter circuit. The resistance act as a load in the circuit which can be varied to study the behavior during light load and heavy load. The different types of input dc sources are used like battery, renewable energy sources etc. The converter is operated at different frequency levels to improve the response of the converters. The various frequency ranges are shown in the Table-1.This paper helps to known the various types of converters, design of converters, and analysis with the help of different software, various control methods to obtain the desired output and so on. This paper gives a brief idea about the starting from the design level to application level. Different types of converters, different operating regions, different application has been mentioned. The various approaches has been mentioned which can help for the researchers to work in that area. Some simulations has been presented with the help of PSIM and MATLAB which adds value to this work. The controller is the brain of the converter system which controls and stable during disturbances. The objective of this paper is to familiar the various process involved during design various kinds of converters.

"2. Converters"

2.1 Classification

Normally, the converters are designed in the medium frequency range. The various types of converter are buck converter, boost converter, inverting and non-inverting buck-boost converter, Cuk-converter, SEPIC converter, full-bridge and half-bridge converter, forward converter, push-pull converter, flyback converter, resonant converter, bidirectional converter and so on. These converters can be classified based on various categories. These converters can be classified as isolated and non-isolated converters, unidirectional and bidirectional converters, step-up and step-down converters, single input and multi-input converters, Low power application and high power application converters etc.

Table-1

Designation	Abbreviation	Frequency Range
Extremely Low Frequency	ELF	3-30Hz
Super Low Frequency	SLF	30-300Hz
Ultra Low Frequency	ULF	300-3000Hz
Very Low Frequency	VLF	3-30KHz
Low Frequency	LF	30-300KHz
Medium Frequency	MF	300KHz-3MHz
High Frequency	HF	3-30MHz
Very High Frequency	VHF	30-300MHz
Ultra High Frequency	UHF	300MHz-3GHz
Super High Frequency	SHF	3-30GHz
Extremely High Frequency	EHF	30-300GHz

There are different modes of operations comes into picture such as continuous conduction mode (CCM), discontinuous conduction mode (DCM), pseudo-continuous conduction mode (PCCM). There are three analysis studied in these converters. Those are steady state analysis, dynamic analysis and transient analysis. The converters are studied based on their efficiency, dynamic response, gain, switch stress, switching loss, robustness, voltage and current ripple, harmonics, wide operating range etc.

2.2 Simulation

Power electronics computer aided simulation and design (PE-CAD) tools play a vital role in the design and analysis of the converters. Various types of software are used to simulate those converters in the initial level. Different types of software are MATLAB, PSIM, PSPICE, SABER, and MULTISIM. There are also different simulations approaches are used for detailed studies such as device level simulation, circuit level simulation and system level simulation. Another classification is device level simulation and ideal level simulation. Different analysis which are available in different simulators are dc analysis (steady state analysis), ac analysis (variation in the parameters), transient analysis (large-signal analysis), periodic steady state analysis, dc sweep analysis, ac sweep/noise analysis, bios point calculation, Monte-Carlo/Worst-Case analysis (useful for sensitive analysis).

2.3 Advantages

The advantages of PE-CAD are: it is possible to study the effects of variations in linear and non-linear elements. There is a provision to obtain "fourier analysis" without using expensive wave form analyzers. It is possible to have optimum design of power electronics circuits. It is possible to identify the performance improvements and/or degradations. Evaluation of the effects of noise and signal distortion without the need for expensive measuring instruments is possible. Sensitive analysis is possible to determine the permissible bounds due to tolerance on every element value or parameters of the active elements.

2.4 Limitations

The various limitations are: they don't support an interactive method of solution. If the elements of a circuit are specified, the response can be predicted. On the other hand, if the response is specified, computer simulation packages can't be used to synthesize the circuit elements. Effects such as electro-magnetic interference (EMI), packaging and thermo-mechanical phenomena are usually not considered in the simulation, although they may have a very important effect on the design of the circuit. Computer simulation packages can't provide 3-D simulation of power electronic circuits where simulation model of electro-mechanical, magnetic, thermal and mechanical properties are sometime critical. They are not interactive, i.e, the circuit can't be analyzed for various component values without any further simulations.

2.5 Filters

All power electronics converters are nothing but filters. Different types of filters give specific name for our convenient. While designing the filters, maximum power transfer theorem is applied to power electronics circuit. Filters can be designed for input port as well as output port. Filters can be classified based on different categories. Based on the frequency, the filters are classified as: low pass filter, high pass filter, band pass filter, band stop filter. Based on the components used, the filters are: analog filters, digital filters, anti-alias filter, and notch filter. Based on the quantity of filtering, the classification is: voltage filter, current filter, ac filter and dc filter. Based on the function, the filters are: EMI filter and line filter. Another classification is active filter and passive filter. The frequency range for which a given filter is to be designed leads to different kinds of filters. Frequency range is related to the amount of power processing in the converters. So filter designs plays an important role in the converter circuit.

"3. Controller"

As we have said the controller is the brain of the converter where the converter is treated as the heart. The converter produces a desired output which is required for the load connected at the output of the converter. Due to the disturbances occur in the converter, the load always not getting the constant desired output. Sometimes, the converter goes unstable which affects the load. So to maintain the required output constant, controller is needed. There are various kind of controllers used in the converter to improve the stability as well as the efficiency. The controllers are also categorized depending upon its use in the converters. It may be analog controller or digital controller. The list of various control methods are voltage mode control, current mode control, proportional control, integral control, derivative control, PID control, adaptive control, pulse-width-modulation control, pulse-skipping modulation control, fuzzy logic control, neural network control, variable structure control, sliding mode control, hysteresis control, fixed frequency boundary control, predictive control etc. Each and every control method has advantages and disadvantages. The use of controller depends on the application. The controllers can be feedback as well as feed-forward. For feedback control, various parameters are fed back and compare with the reference values. The feedbacks parameters are output voltage, load current, inductor current etc. Different controllers can also be combined to improve the response. Such combinations are like sliding mode controllers with constant switching frequency, fixed-frequency Pulsewidth modulation based quasi-sliding mode control, PWM based sliding mode control, neuro-fuzzy control. The aim of all type of controllers is to operate the converter in the desired output range and there should be minimum effect due to the external disturbances.

"4. Recent Converters"

The recent converters are the modifications of the basic converter which increases the operating regions. The converters can be modified by adding inductor and capacitor which increases the order of the converters. Some examples are adaptive hysteresis control of 3rd order buck converter, predictive controller for fourth order buck converter etc. Multi-input converter can be obtained by adding more than one input sources in the converter. So rigorous study is required by applying different control methods.

4.1 Bidirectional Converter

One such type of converter is bidirectional buck-boost converters. In this type of converters, one direction is used to step-up the voltage and another direction is used to step-down the voltage. It is like the charging and discharging of the converter. It can be operated in CCM as well as DCM.

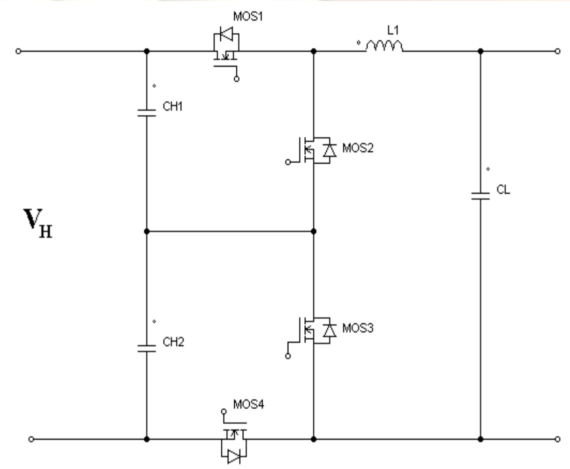

Fig. 1 Bidirectional dc-dc converter

The Fig.1 shows one of the bidirectional dc-dc converter. It is using four controlled switching devices. The left side of the converter is used as high voltage side and right hand side is used as low voltage side. Two capacitors with same rating are used in the high voltage side to maintain the half of the input voltage constant. A lot of work is done for designing the conververter. But few work has been done for controlling this converter. The logic can be developed where the converter can operate buck or boost mode where the power is flowing from left to right. Similarly, the logic can also be developed to operate the converter in buck as well as boost mode during right to left power flow. The converter is studied in CCM mode and DCM mode which can be extended to PCCM mode. Another such type of converter is shown in Fig.2 where coupled inductor is unsed to transfer the power. Mostly, these type of converters has ben stuided to increase the voltage gain and low power applications. Other areas like improvement of transient response, stability analysis need to be studied.

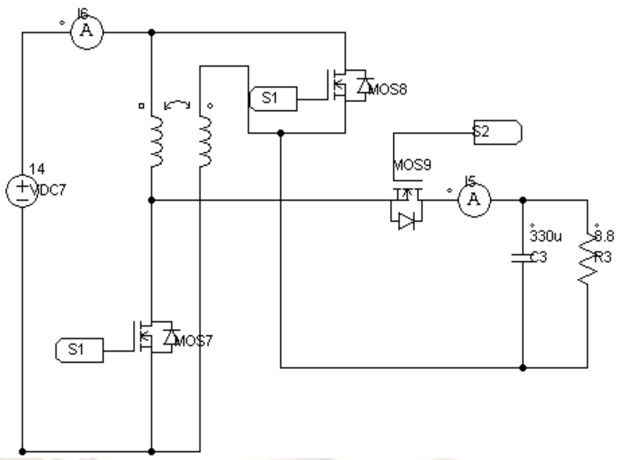

Fig. 2 Bidirectional dc-dc converter with coupled inductor

4.2 Transformer-less dc-dc converter

In the Fig. 2, the controlled switch which is connected in the load side is replaced by the diode and it is represented in Fig. 3. This converter describes the CCM and DCM operation with high step up voltage gain.

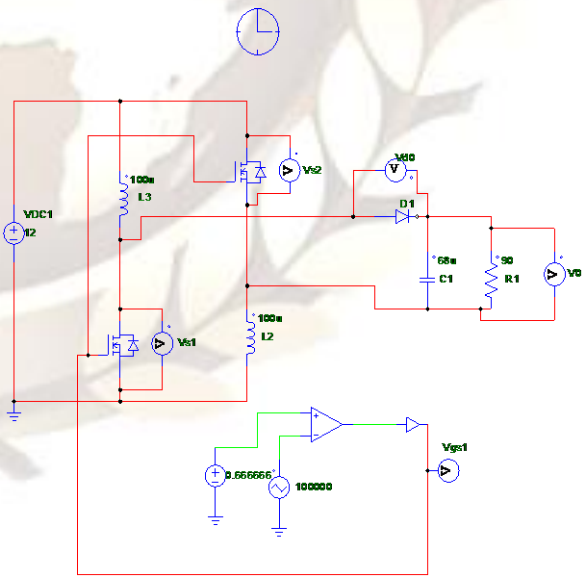

Fig. 3 High step up dc-dc converter

Fig.4. Simulation result of output voltage, diode voltage and switch voltage

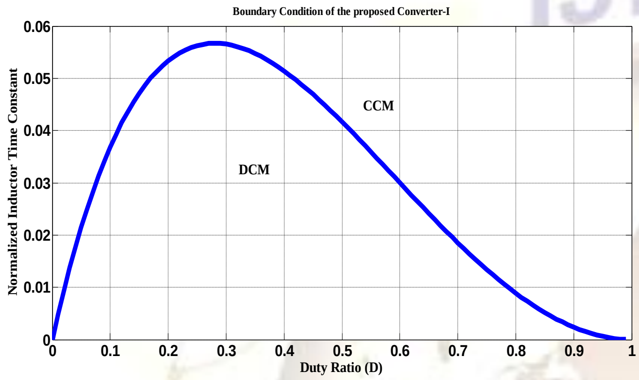

Fig.5. Boundary condition of the converter

Fig.5 shows the operating region of DCM and CCM with the boundary condition. The circuit is simulated in the open loop condition.

4.3 A step down dc-dc converter with low output voltage and high output current application

The Fig. 6 shows the converter which is applicable for low output voltage and high output current application. The voltage gain of the proposed converter is half of the conventional buck converter with reduced current stresses on power devices and low output-current ripple are reduced. The proposed converter can achieve high step-down voltage gain with appropriate duty ratio. The two switches interleaved controlled converter inhibits a self-current balanced characteristics and thus no current balanced controlled circuit is required.

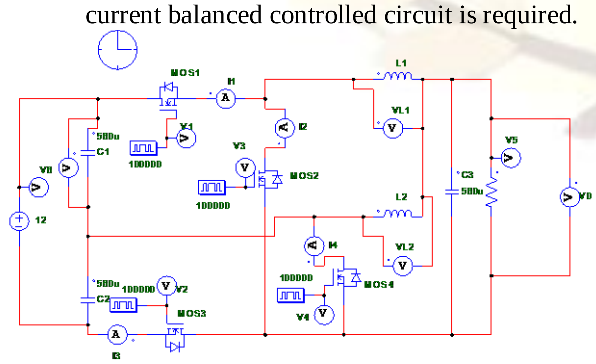

Fig.6. dc-dc step-down converter

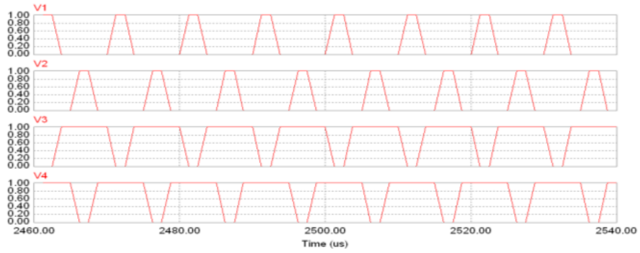

Fig.7. Voltage across each controlled switch

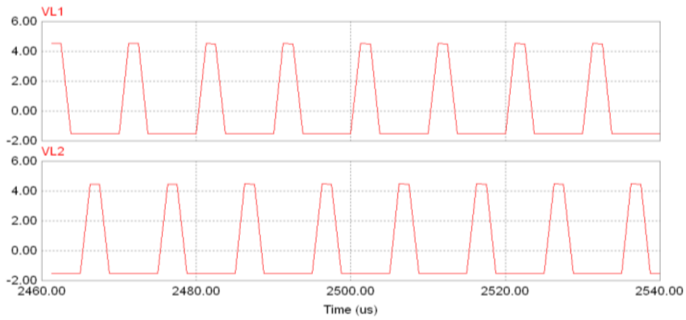

Fig.8. Voltage across inductor L1 and L2

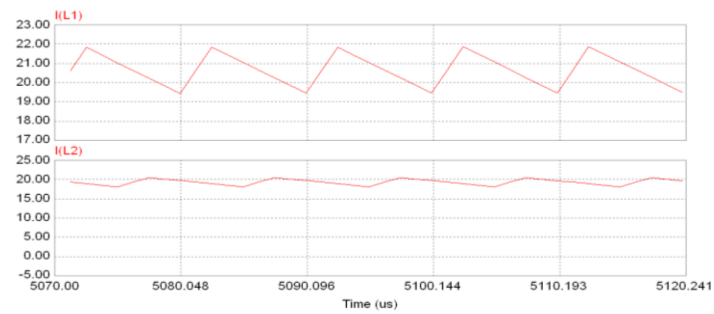

Fig.9. Current across inductor L1 and L2

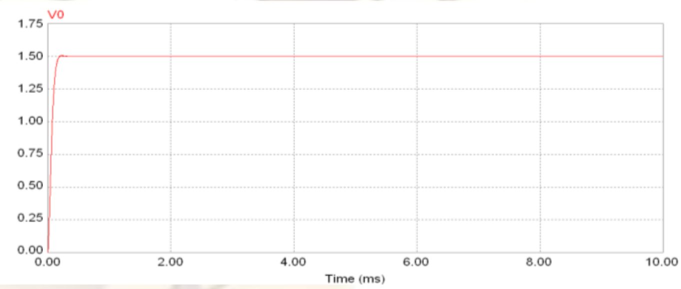

Fig.10. Output Voltage

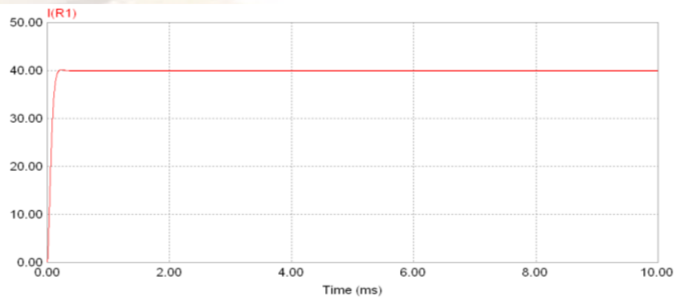

Fig.10. Output Current

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The Fig. 7 to 10 shows various waveform the converter after simulating the converter in the PSIM. A control method can be applied to this converter to continue research in this converter. The circuit parameters which are used during simulation are Vin=12V, Vo=1.5V,D=0.25, Io=40A, Fs=100KHz, C1=C2=560μF, L1=L2=4.7μH, Co=560μF. The voltage gain=G=Vo/Vin=D/2.

4.4 A novel high step-up dc-dc converter for a micro-grid system

A proposed novel high step-up dc-dc converter for a distributed generation system is shown in the Fig.11. The efficiency of the converter is improved by reducing the reverse-recovery problem of the diode. The voltage stresses on the main switch and output diode are reduced by a passive clamp circuit. The proposed converter adds two pairs of additional capacitors and diodes to achieve high step-up voltage gain. Two capacitors are charged in parallel and discharged in series by the coupled inductor to achieve high step-up voltage gain with an appropriate duty ratio. The advantages of the proposed converter are:-

(a) It has low conduction loss.
(b) It allows significant weight and volume reduction compared with other converter.
(c) Voltage stresses on the main switch and output diode are reduced.
(d) Reverse-recovery problems in the diodes are alleviated, and thus high efficiency can be achieved.

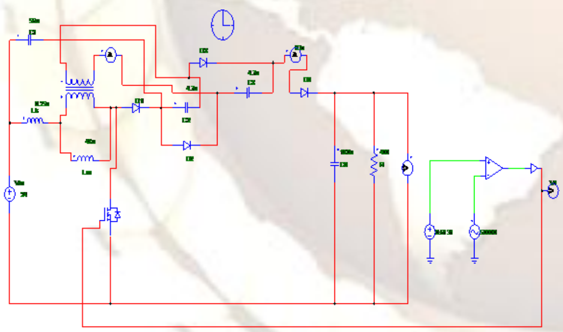

Fig.11. A novel high step-up dc-dc converter

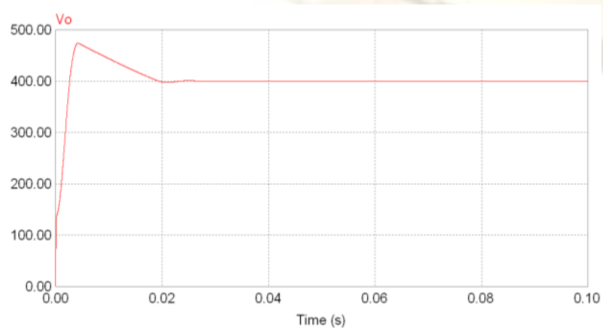

Fig.12. Output Voltage

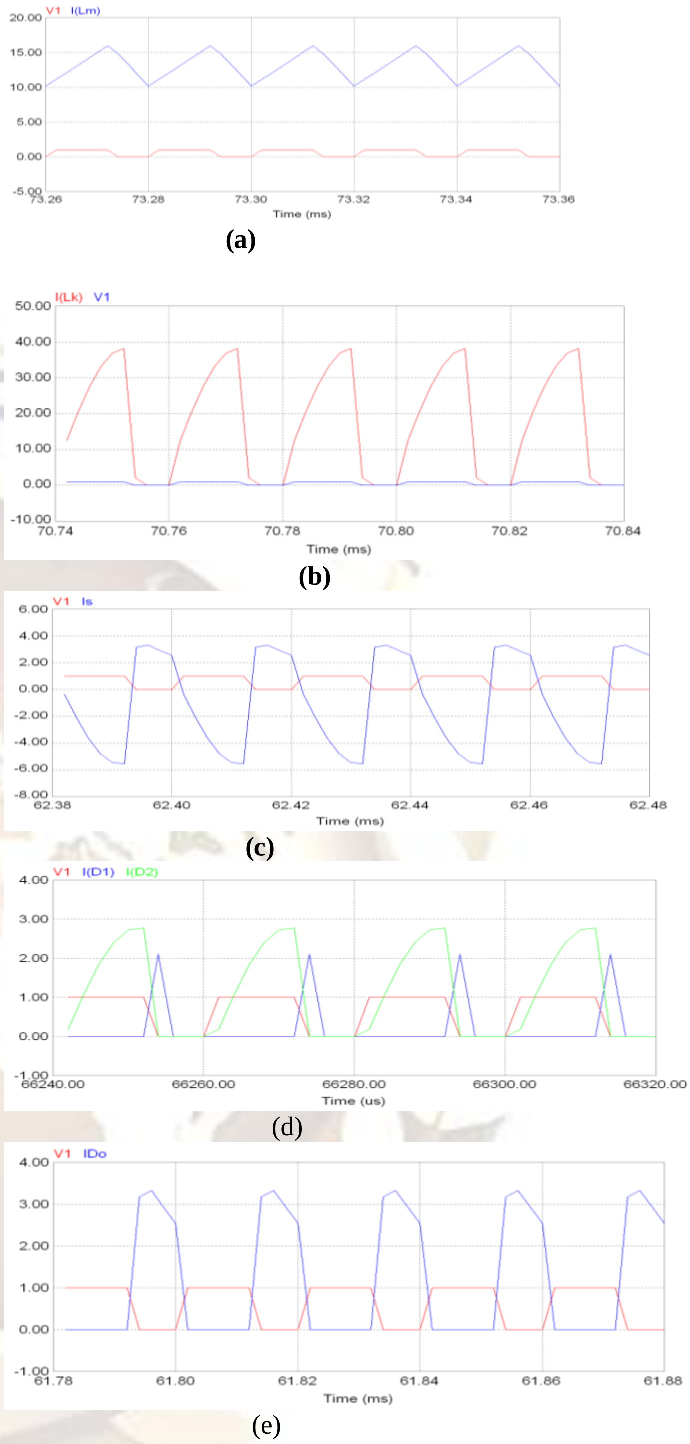

Fig.13 (a), (b), (c), (d), (e) shows various waveforms obtained from the converter

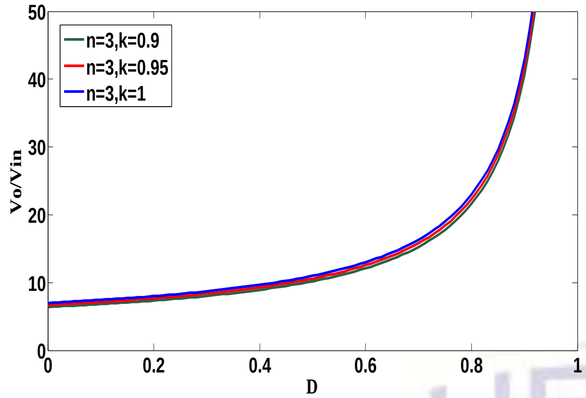

Fig.13. Voltage gain versus duty ratio at CCM operation

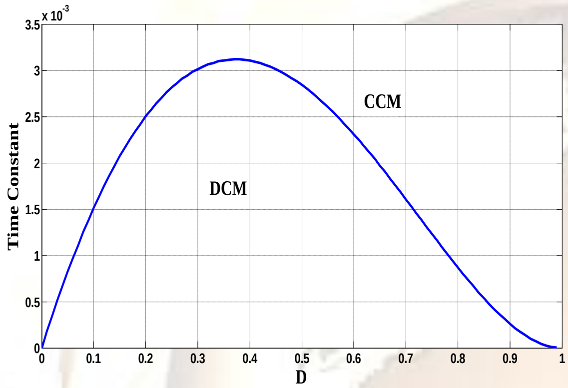

Fig.14. Boundary condition of the proposed converter

"5. Conclusion"

This paper gives a brief study on the design of the converter and various control methods are mentioned. The role of controller is important while it is using for a particular application. Various filter selection helps to reduce the harmonics in the converter. Different simulations are used for different analysis. Various converters are designed based on the basic converters by modifying the circuit parameters. Steady state and transient analysis is essential for the converter during disturbances. Some of those converters are simulated and presented in this paper. It is not so difficult to analyze a converter and apply control method to those converters. Various areas can be elaborated with a single converter. This paper helps as a guideline to study the dc-dc converters. The converters can be analyzed by using state space analysis which is not mentioned in this paper. The converter as well as the controller can be converted into digital domain.

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