A Review of Design, Development, Control and Applications of DC−DC Converters

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Abstract: The DC−DC converters have become research interest due to high utilization in various applications. The DC−DC converter is required to change DC electrical energy from one voltage level to another voltage level efficiently. A DC−DC converters are widely used in DC motor drive applications and in regulated switched mode DC power supplies. This paper presents a comprehensive review on various types of DC−DC converters with their recent progress, development and features. In this age of modern electronics, the smart devices, gadgets, solar PV system and Internet of things (IoT) require appropriate DC level voltage conversion, control and regulation. This review is concluded with future aspects and applications with reference to DC−DC converters.

Keywords: DC–DC converter, SMPS, Classification, Voltage Regulation.

I Introduction

Modern power supply system represent the conversation of different level of voltages for every circuit designer across the electrical designs. For smart sensors, Internet of Things (IoT), transportation, medical, automation, gadgets and fitness circuit solutions, one of the elementary challenging task is to design an appropriate power-supply circuit network. Power-supply is categorized into many levels, at the top level are the basic AC−AC, AC−DC, DC−AC and DC−DC converters. Modern electronic devices require DC−DC conversion in terms of shifting the power signal down with a low-dropout regulator (LDO) or buck topologies, and up with a boost topology.

Nowadays, the Switched-Mode Power Supply (SMPS) [1] plays an important role in the consumer power market. With its small size, it can be found everywhere from mobile phone chargers to Plasma TVs. It is used to convert the electricity from one voltage/current to the other voltage/current. For a simple example, a mobile phone charger converts the electricity from the plug with around 220 V AC to 9 V DC to supply the mobile phone [2].

Typically, the SMPS solution consists of several electronic components: a switching controller, a power MOSFET, a transformer, diodes, resistors, capacitors and inductors. In order to obtain the complete SMPS design, a long list of calculations has to be done in order to figure out the appropriate value for all electronic components [3].

1.1 Switched-Mode Power Supply (SMPS)

This can hardly ideate the lifestyle without the provision and processing activities which use electrical energy, and its supply. A host of devices in everyday use are operated either directly from the mains power grid, from the vehicle power supply in an automobile or using accumulators. The electronic circuits in modern devices in entertainment, data processing or industrial electronics are mostly supplied with direct voltages from 12 V down to below 1 V. To be able to operate these devices from the common alternating voltage mains network, or to change up the internal accumulators, a power supply is required [4, 5].

Conventional power supply consists of a mains transformer for voltage reduction and galvanic isolation from the mains, a rectifier for producing a direct voltage and a bulk capacitor for voltage smoothing.

1.2 Architecture of The Switched-Mode Power Supplies

Switched-mode power supplies (SMPS) are power supplies which chop the rectified and filtered mains voltage at a frequency which is significantly higher than the 50 Hz of the mains alternating current as shown in Figure 1.

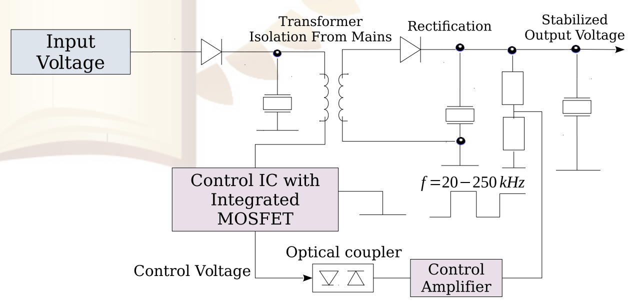

Figure 1: Switched-Mode Power Supply

By using the semiconductor switches exclusively only switching and forward losses arise. This is responsible for the characteristically high efficiency of a pulsed power supply by comparison with analog methods. Regulation is effected either by altering the pulse duty factor at a constant frequency, or by changing the frequency for a fixed or variable pulse duty factor [6]. The voltage chopped in this way can be transformed to any other required voltage, and rectified. The ferrite core transformer serves not only to make the required voltage conversion and provide galvanic isolation from the mains supply but also, depending on its working principle, to store the magnetic energy [7].

With SMPS, the pulsing results in harmonic waves, which can cause radiated interference to radio and TV reception, as well as to communication transmissions. Legislation demands a limit on the interference signal levels for all electrical devices and systems which produce high frequency energy [8].

An SMPS which is powered from the alternating voltage mains and which supplies a DC voltage at its output is also called an AC−DC converter. If a direct current source (e.g. an AC−DC converter, or a battery) is connected to the input, then we speak of a DC−DC converter, or a switching regulator [9]. If the voltage is not rectified at the output, the device is a DC-AC converter or inverter. If the SMPS is supplied from the mains, and there is no rectification on the output side, we have an AC−AC converter, i.e. an alternating current converter [10].

1.3 Operation Principle and Circuit System of Switching Power Supply

As mentioned above, stabilization mode of power supply is roughly classified into switching mode and series mode. Nowadays, power supply means switching system in many cases due to high efficiency and compact [11]. Here, the mechanism of switching power supply is explained.

1.3.1 Operation Principle

Basic circuit and components of switching power supply is shown in Figure 2.

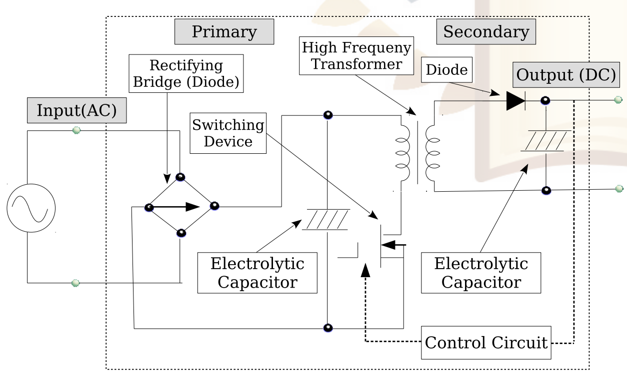

Figure 2: Basic Circuit and Components of Switching Power Supply

- Rectifying bridge: To rectify AC current to one direction.
- Electrolytic capacitor: To build up electricity and work to keep voltage.
- High frequency transformer: To transfer energy from primary to secondary.
- Control circuit: To control ON/OFF timing of switching device to stabilize secondary voltage.

In this system, input (alternate current: AC) is converted to output (direct current: DC). Input side is called "Primary" output side is called "Secondary" to which energy is transferred via high frequency transformer.

Now, referring to the diagram above, operation mechanism of switching power supply can be explained as follows,

1. Connect alternate current (AC) to switching power supply.
2. The AC is rectified by rectifying bridge and smoothed by primary electrolytic capacitor after that.
3. Switching operation (repeated electric ON/OFF operation) of switching device generates alternate current with high frequency.
4. Energy (AC) is transferred via high frequency transformer to secondary side.
5. Rectified by secondary diode and smoothed by secondary electrolytic capacitor, the energy is converted to DC (direct current) as output.
6. To keep output voltage stabilized, switching is controlled through feedback system.

That is the basic operation principle of switching power supply.

II Background and Review

There are various methods in switching power supply depends on DC−DC converter's mode which converts DC to AC with high frequency, and again converts it back to DC [12]. Also, in determining switching cycle of DC−DC converter, it is classified into two modes. One is called self-excitation mode whose switching block determines the switching cycle on its own [13]. The other method is called separate excitation mode (PWM mode) that has an oscillator to decide the frequency independently. Self-excitation mode's features are "Cost is low due to simple circuit structure," and "the frequency changes according to input voltage and load condition" [14, 15].

Separate excitation mode's features are "Cost is generally high compared to self-excitation mode as it uses ICs", and "the frequency is constant". Also, there are another two modes when energy is transferred from primary to secondary [16]. One is called forward mode where the energy is transferred during ON period, and the other is called fly back mode where the energy is transferred during OFF period [17][18].

2.0.1 Single Forward DC−DC Converter

This mode is used in many switching power supplies due to simple structure and stable control as presented in Figure 3. (Adopted in our Nonstop power supplies in many cases). Separate excitation mode is mostly used from small power to high power as well. Disadvantage is poor usability of transformer [19, 20].

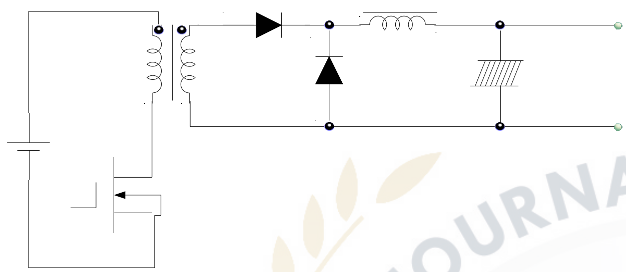

Figure 3: Single Forward DC−DC Converter

2.0.2 Flyback DC−DC Converter (RCC)

This mode need a few components and is the simplest mode, but not suitable to high power. This is mostly adopted to small power, but input voltage range is wide as presented in Figure 4 [21, 22].

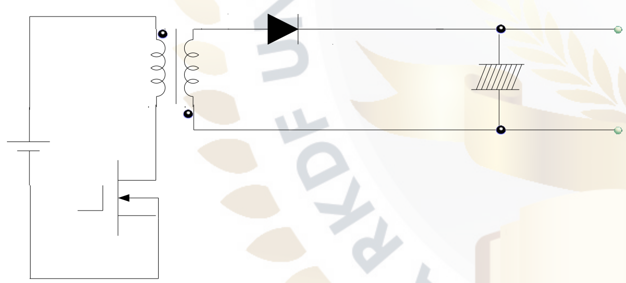

Figure 4: Flyback DC−DC Converter

2.0.3 Push-Pull DC−DC Converter

This mode uses two switching devices and coils to turn on alternately. Bias magnetism of transformer is critical as presented in Figure 5 [23, 24].

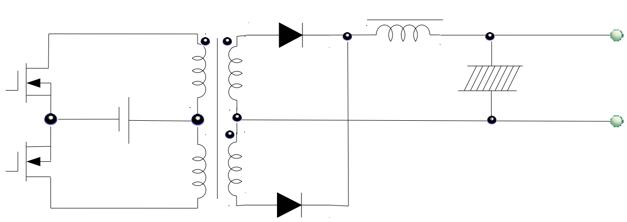

Figure 5: Push-Pull DC−DC Converter

2.0.4 Half-Bridge DC−DC Converter

Operation is the same as push-pull mode, but as the applied to transform is half of V_i, low voltage transistors can be used [25]. The usability of transformer is better, but the temperature rise of each capacitor caused by switching current that flows in capacitors is critical as presented in Figure 6 [26, 27].

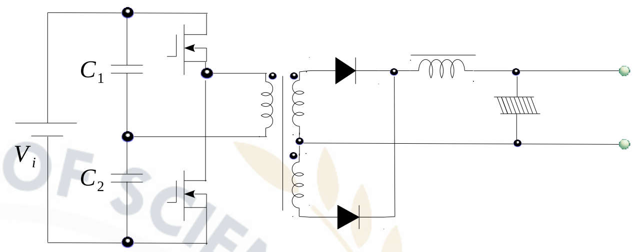

Figure 6: Half-Bridge DC−DC Converter

2.0.5 Full-Bridge DC−DC Converter

Circuit structure is complicated, but low voltage switching devices can be used as presented in Figure 7. It gives high efficiency and is ado improve the tracking capability of the PV, soft computing technique is used to utilize the PV power effectively. Here, DPSO is used to maximize the PV power. In this paper Performance of SEPIC converter compared with buck-boost converter under both normal and partial shading conditions of PV system. This paper gives the new intelligent control technique in order to track the global maxima of PV power effectively and also gives MATLAB-Simulink to control the system parameters via DPSO method. opted to high power [28]. Usability of transformer is the highest of all. Critical points are bias magnetism and penetration current between upper and lower devices (FETs) [29, 30].

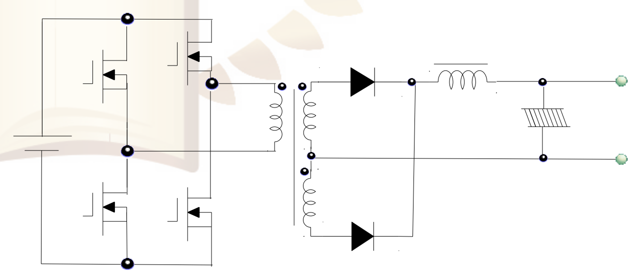

Figure 7: Full-Bridge DC−DC Converter

III Applications and Classifications

The main applications fields for SMPS are:

- Consumer electronics: TVs, DVD players, video recorders, set top boxes, satellite receivers, chargers and external power supply units.
- Electronic DP: PCs, servers, monitors, notebooks.
- Telecommunications: mobile communication base stations, switching stations, mobile phone chargers.
- Industrial electronics: open and closed loop control engineering, measuring instruments, auxiliary power supplies, battery chargers etc.

3.1 Advantages and Disadvantages

The main advantage of this method is greater efficiency because the switching MOSFET dissipates little power when it is outside of its active region (i.e., when the MOSFET acts like a switch and either has a negligible voltage drop across it or a negligible current through it). Other advantages include smaller size and lighter weight (from the elimination of low frequency transformers which have a high weight) and lower heat generation due to higher efficiency.

Disadvantages include greater complexity, the generation of high-amplitude, high-frequency energy that the low-pass filter must block to avoid electromagnetic interference (EMI), and a ripple voltage at the switching frequency and the harmonic frequencies thereof. Very low cost SMPS may couple electrical switching noise back onto the mains power line, causing interference with A/V equipment connected to the same phase. Non power-factor-corrected SMPS also cause harmonic distortion.

3.2 Classification of SMPS

Switched-mode power supplies can be classified according to the circuit topology. The most important distinction is between isolated converters and non-isolated ones.

3.2.1 Non-Isolated Topologies

Non-isolated converters are simplest, with the three basic types using a single inverter for energy storage [31]. In the Voltage relation column, D is the duty cycle of the converter, and can vary from 0 to 1. V_{in} is assumed to be greater than zero; if it is negative, negate V_{out} to match. The list of Non-isolated topology is listed below in Table 1 [32].

Table 1: Non-Isolated Topologies

Type	Power [Watts]	Typical Efficiency	Relative Cost	Energy Storage	Voltage Relation	Features
Buck	0-1000	75%	1.0	Single Inductor	$0 \leq \text{Out} \leq \text{In}$, $\text{Out} = \text{In} \times D$	Continuous Output
Boost	0-150	78%	1.0	Single Inductor	$\text{Out} \geq \text{In}$, $\text{Out} = \frac{\text{In}}{(1-D)}$	Continuous Input
Buck-Boost	0-150	78%	1.0	Single Inductor	$Out \leq 0$, $\text{Out} = -\text{In} \times \frac{D}{(1-D)}$	Inverted Output Voltage

The buck, boost, and buck-boost topologies are all strongly related. Input, output and ground come together at one point. One of the three passes through an inductor on the way, while the other two pass through switches. One of the two switches must be active (e.g. a MOSFET), while the other can be a diode [33][34]. Sometimes, the topology can be changed simply by re-labeling the connections. A 12 V input, 5 V output buck converter can be converted to a 7 V input, -5 V output buck-boost by grounding the "output" and taken the output from the "ground" pin. Switching becomes less efficient as duty cycles become extremely short. For large voltage changes, a transformer (isolated) topology may be better [35, 36].

3.2.2 Isolated Topologies

All isolated topologies include a transformer, and thus can produce an output of higher or lower voltage than the input by adjusting the turn's ratio [37]. For some topologies, multiple windings can be placed on the transformer to produce multiple output voltages. Some converters use the transformer for energy storage, while others use a separate inductor [38].

Table 2: Isolated Topologies

Type	Power [Watts]	Typical Efficiency	Relative Cost	Input Range	Energy Storage	Features
Fly-back	0-250	78%	1.0	5-600 V	Transformer	Isolated form of Boost converter
Half-Forward	0-250	75%	1.2	5-500 V	Inductor	
Forward		78%		60-200 V	Inductor	Isolated form of Buck converter
Push-Pull	100-1000	72%	1.75	50-1000 V	Inductor	
Half Bridge	0-2000	72%	1.9	50-1000 V	Inductor	
Full Bridge	400-5000	69%	> 2.0	50-1000 V	Inductor	Very efficient use of transformer

IV Proposed Methodology

Modern electronics, the smart devices, gadgets, solar PV system and Internet of things (IoT) require appropriate DC level voltage conversion, control and regulation. For improving the conversion and control efficiency, soft computing techniques like fuzzy logic, neural network, genetic algorithm, artificial intelligence techniques etc. are required to utilize effectively. These methods can be used to maximize the solar PV power. Soft computing establish the new intelligent control technique in order to regulate smart electronic devices and maximize the PV system power effectively.

V Conclusion

Soft computing based DC−DC converter for discontinuous and continuous conduction mode significantly improve the conversion process. The unique features is the comparison of time response specification among two controllers for different input voltage. The linearized model of DC−DC converter is obtained by using state space averaging technique. The values of time domain specifications have improved more in fuzzy logic controller rather in PI controller.

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