A Review Paper of Switched Mode Power Supplied using Multiples Converter

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Abstract— In this era due to Power electronics revolution, people have very efficient tools to solve problems of having DC voltage to power the Electronics Devices. Every new electronic product requires converting input voltage 230V AC power to some fixed DC voltage for powering the electronics circuit or devices. Switching regulators (SMPS) are becoming an essential part of many electronic systems due to miniaturization and energy efficiency. Conventional power supplies, however, draw currents that are highly non-sinusoidal and out of phase with input voltage, thus display a low power factor and higher total harmonic distortion (THD), which causes power quality problems. In This work presents two stage AC-DC and DC-DC power converter using single-phase isolated Full bridge converter with inherent power factor correction (PFC) method for switched mode power supply (SMPS).The advantages of the proposed methodology are its simple control strategy, reduction in complexity of system, low input line current harmonics. The effect of load variation on SMPS is also studied in order to demonstrate the effectiveness of converter for the complete range of load conditions.

Key words: DC to DC Converter, DC to AC Converter, SMPS

I. INTRODUCTION

An S.M.P.S. can be a fairly complicated circuit as can be seen from the block diagram shown in Fig. 1. (This configuration assumes a 50/60Hz mains input supply is used.) The ac supply is first rectified, and then filtered by the input reservoir capacitor to produce a rough dc input supply. This level can fluctuate widely due to variations in the mains. In addition the capacitance on the input has to be fairly large to hold up the supply in case of a severe drop in the mains. (The S.M.P.S. can also be configured to operate from any suitable dc input, in this case the supply is called a dc to dc converter.), The unregulated dc is fed directly to the central block of the supply, the high frequency power switching section. Fast switching power semiconductor devices such as MOSFETs and Bipolar are driven on and off, and switch the input voltage across the primary of the power transformer. The drive pulses are normally fixed frequency (20 to 200kHz) and variable duty cycle. Hence, a voltage pulse train of suitable magnitude and duty ratio appears on the transformer secondary. This voltage pulse train is appropriately rectified, and then smoothed by the output filter, which is either a capacitor or capacitor /inductor arrangement, depending upon the topology used. This transfer of power has to be carried out with the lowest losses possible, to maintain efficiency. Thus, optimum design of the passive and magnetic components, and selection of the correct power semiconductors is critical Regulation of the output to provide a stabilized dc supply is carried out by the control / feedback block. Generally, most S.M.P.S. systems operate on a fixed frequency pulse width modulation basis, where the duration of the on time of the drive to the power switch is varied on a cycle by cycle basis. This compensates for changes in the input supply and output load. The output voltage is compared to an accurate reference supply, and the error voltage produced by the comparator is used by dedicated control logic to terminate the drive pulse to the main power switch/switches at the correct instance. Correctly designed, this will provide a very stable dc output supply. It is essential that delays in the control loop are kept to a minimum, otherwise stability problems would occur. Hence, very high speed components must be selected for the loop. In transformer-coupled supplies, in order to keep the isolation barrier intact, some type of electronic isolation is required in the feedback. This is usually achieved by using a small pulse transformer or an op to -isolator, hence adding to the component count. In most applications, the S.M.P.S. topology contains a power transformer. This provides isolation, voltage scaling through the turns ratio, and the ability to provide multiple outputs. However, there are non-isolated topologies (without transformers) such as the buck and the boost converters, where the power processing is achieved by inductive energy transfer alone. All of the more complex arrangements are based on these non-isolated types.

II. BASIC SWITCHED MODE SUPPLY CIRCUIT

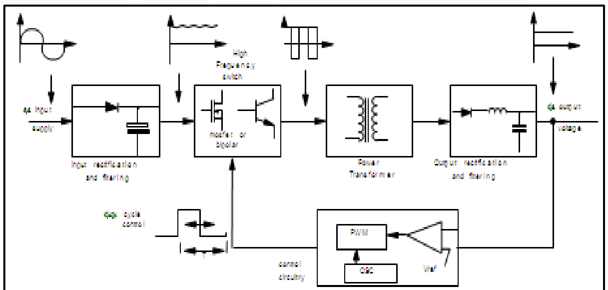

Fig. 1. Basic switched mode power supply block diagram.

A. Non-Isolated Converter

The majority of the topologies used in today's converters are all derived from the following three non-isolated versions called the buck, the boost and the buck-boost. These are the simplest configurations possible, and have the lowest component count, requiring only one inductor, capacitor, transistor and diode to generate their single output. If isolation between the input and output is required, a transformer must be included before the converter.

1) The Buck Converter

The forward converter family which includes the push-pull and bridge types, are all based on the buck converter, shown in Fig. 2. Its operation is straightforward. When switch TR1 is turned on, the input voltage is applied to inductor L1 and power is delivered to the output. Inductor current also builds up according to Faraday's law shown below:-

When the switch is turned off, the voltage across the inductor reverses and freewheel diode D1 becomes forward biased. This allows the energy stored in the inductor to be delivered to the output. This continuous current is then smoothed by output capacitor Co. Typical buck waveforms are also shown in Fig. 2.

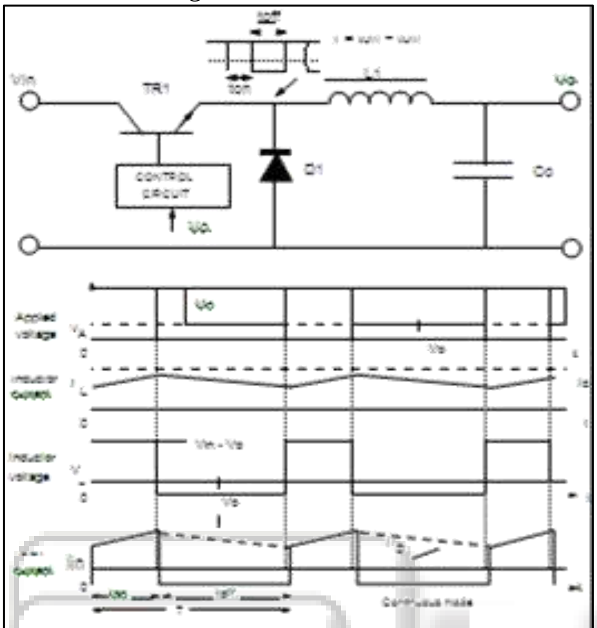

Fig. 2 Buck Regulator (step-down).

The LC filter has an averaging effect on the applied pulsating input, producing a smooth dc output voltage and current, with very small ripple components superimposed. The average voltage/sec across the inductor over a complete switching cycle must equal zero in the steady state. (The same applies to all of the regulators that will be discussed.)

Neglecting circuit losses, the average voltage at the input side of the inductor is $V_{in}D$, while V_O is the output side voltage. Thus, in the steady state, for the average voltage across the inductor to be zero, the basic dc equation of the buck is simply:-

$$V_O/V_{in} \ . \ D$$

Thus, the buck is a step down type, where the output voltage is always lower than the input. (Since D never reaches one.) Output voltage regulation is provided by varying the duty cycle of the switch. The LC arrangement provides very effective filtering of the inductor current. Hence, the buck and its derivatives all have very low output ripple characteristics. The buck is normally always operated in continuous mode (inductor current never falls to zero) where peak currents are lower, and the smoothing capacitor requirements are smaller. There are no major control problems with the continuous mode buck.

2) The Boost Converter

Operation of another fundamental regulator, the boost, shown in Fig. 3 is more complex than the buck. When the switch is on, diode D1 is reverse biased, and V_{in} is applied across inductor, L1. Current builds up in the inductor to a peak value, either from zero current in a discontinuous mode, or an initial value in the continuous mode. When the switch turns off, the voltage across L1 reverses, causing the voltage at the diode to rise above the input voltage. The diode then conducts the energy stored in the inductor, plus energy direct from the supply to the smoothing capacitor and load. Hence, V_O is always greater than V_{in}, making this a step-up converter. For continuous mode operation, the boost dc equation is obtained by a similar process as for the buck, and is given below:-

$$\frac{V_O}{V_i} \qquad \frac{1}{1\ D}$$

Again, the output only depends upon the input and duty cycle. Thus, by controlling the duty cycle, output regulation is achieved.

From the boost waveforms shown in Fig. 3, it is clear that the current supplied to the output smoothing capacitor from the converter is the diode current, which will always be discontinuous. This means that the output capacitor must be large, with a low equivalent series resistance (e.s.r) to produce a relatively acceptable output ripple. This is in contrast to the buck output capacitor requirements described earlier. On the other hand, the boost input current is the continuous inductor current, and this provides low input ripple characteristics. The boost is very popular for capacitive load applications such as photo-flashers and battery chargers. Furthermore, the continuous input current makes the boost a popular choice as a pre-regulator, placed before the main converter. The main functions being to regulate the input supply, and to greatly improve the line power factor. This requirement has become very important in recent years, in a concerted effort to improve the power factor of the mains supplies.

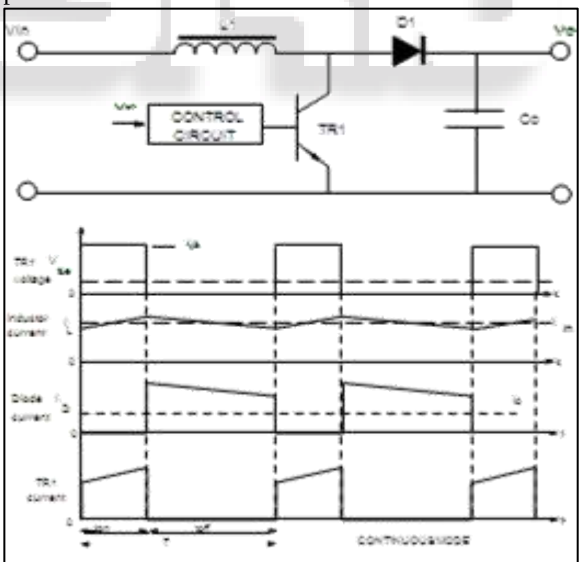

Fig. 3 Boost Regulator (step-up).

If the boost is used in discontinuous mode, the peak transistor and diode currents will be higher, and the output capacitor will need to be doubled in size to achieve the same output ripple as in continuous mode. Furthermore, in discontinuous operation, the output voltage also becomes dependent on the load, resulting in poorer load regulation.

Unfortunately, there are major control and regulation problems with the boost when operated in continuous mode. The pseudo LC filter effectively causes a complex second order characteristic in the small signal (control) response. In the discontinuous mode, the energy in the inductor at the start of each cycle is zero. This removes the inductance from the small signal response, leaving only the output capacitance effect. This produces a much simpler response, which is far easier to compensate and control.

3) The Buck-Boost Regulator (Non-isolated Flyback)

The very popular flyback converter is not actually derived solely from the boost. The flyback only delivers stored inductor energy during the switch off-time. The boost, however, also delivers energy from the input. The flyback is actually based on a combined topology of the previous two, called the buck-boost or none isolated flyback regulator. This topology is shown in Fig. 4.

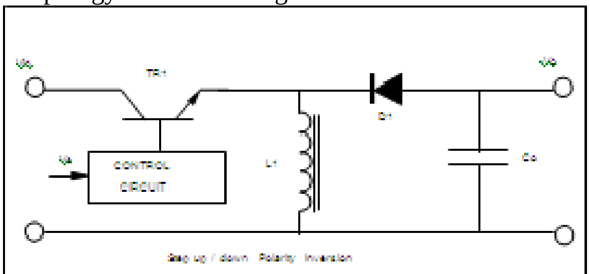

Fig. 4 Buck-Boost (Flyback) Regulator.

When the switch is on, the diode is reverse biased and the input is connected across the inductor, which stores energy as previously explained. At turn-off, the inductor voltage reverses and the stored energy is then passed to the capacitor and load through the forward biased rectifier diode.

The waveforms are similar to the boost except that the transistor switch now has to support the sum of Vin and Vo across it. Clearly, both the input and output currents must be discontinuous. There is also a polarity inversion, the output voltage generated is negative with respect to the input. Close inspection reveals that the continuous mode dc transfer function is as shown below:-

$$\frac{V}{1\text{-}D}$$

Observation shows that the value of the switch duty ratio, D can be selected such that the output voltage can either be higher or lower than the input voltage. This gives the converter the flexibility to either step up or step down the supply.

This regulator also suffers from the same continuous mode control problems as the boost, and discontinuous mode is usually favoured.

Since both input and output currents are pulsating, low ripple levels are very difficult to achieve using the buck-boost. Very large output filter capacitors are needed, typically up to 8 times that of a buck regulator.

The transistor switch also needs to be able to conduct the high peak current, as well as supporting the higher summed voltage. The flyback regulator (buck-boost) topology places the most stress on the transistor. The rectifier diode also has to carry high peak currents and so the r.m.s conduction losses will be higher than those of the buck.

STANDARD ISOLATED TOPOLOGIES.

(a) THE FLY-BACK CONVERTER.

OPRATION

Of all the isolated converters, by far the simplest is the single-ended flyback converter shown in Fig. 6. The use of a single transistor switch means that the transformer can only be driven unipolar (asymmetrical). This results in a large core size. The flyback, which is an isolated version of the buck-boost, does not in truth contain a transformer but a coupled inductor arrangement. When the transistor is turned on, current builds up in the primary and energy is stored in the core, this energy is then released to the output circuit through the secondary when the switch is turned off. (A normal transformer such as the types used in the buck derived topologies couples the energy directly during transistor on-time, ideally storing no energy).

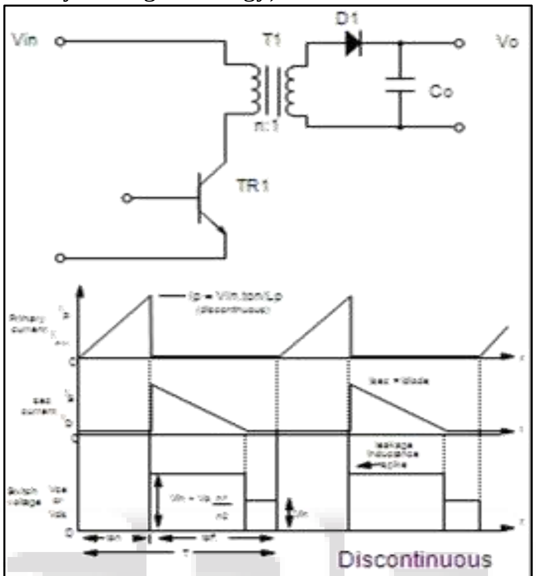

Fig. 6 Flyback converter circuit and waveforms.

The polarity of the windings is such that the output diode blocks during the transistor on time. When the transistor turns off, the secondary voltage reverses, maintaining a constant flux in the core and forcing secondary current to flow through the diode to the output load. The magnitude of the peak secondary current is the peak primary current reached at transistor turn-off reflected through the turns ratio, thus maintaining a constant Ampere-turn balance.

The fact that all of the output power of the flyback has to be stored in the core as $1/2LI^2$energy means that the core size and cost will be much greater than in the other topologies, where only the core excitation (magnetisation) energy, which is normally small, is stored. This, in addition to the initial poor unipolar core utilisation, means that the transformer bulk is one of the major drawbacks of the flyback converter.

In order to obtain sufficiently high stored energy, the flyback primary inductance has to be significantly lower than required for a true transformer, since high peak currents are needed. This is normally achieved by gapping the core. The gap reduces the inductance, and most of the high peak energy is then stored in the gap, thus avoiding transformer saturation.

When the transistor turns off, the output voltage is back reflected through the transformer to the primary and in many cases this can be nearly as high as the supply voltage energy in the transformer leakage inductance. This means that the transistor must be capable of blocking approximately twice the supply voltage plus the leakage spike. Hence, for a 220V ac application where the dc link can be up to 385V, the transistor voltage limiting value must lie between 800 and 1000V.

Using a 1000V Bipolar transistor such as the BUT11A or BUW13A allows a switching frequency of 30 kHz to be used at output powers up to 200Watts.

MOSFETs with 800V and 1000V limiting values can also supply 100W at switching frequencies anywhere up to 300kHz. Although the MOSFET can be switched much faster and has lower switching losses, it does suffer from significant on-state losses, especially in the higher voltage devices when compared to the bipolar. An outline of suitable transistors and output rectifiers for different input and power levels using the fly back is given in Table 2.

One way of removing the transformer leakage voltage spike is to add a clamp winding as shown in Fig. 8. This allows the leakage energy to be returned to the input instead of stressing the transistor. The diode is always placed at the high voltage end so that the clamp winding capacitance does not interfere with the transistor turn-on current spike, which would happen if the diode was connected to ground. This clamp is optional and depends on the designer’s particular requirements.

B. Advantages

The action of the fly back means that the secondary inductance is in series with the output diode when current is delivered to the load; i.e driven from a current source. This means that no filter inductor is needed in the output circuit. Hence, each output requires only one diode and output filter capacitor. This means the fly back is the ideal choice for generating low cost, multiple output supplies. The cross regulation obtained using multiple outputs is also very good (load changes on one output have little effect on the others) because of the absence of the output choke, which degrades this dynamic performance.

The flyback is also ideally suited for generating high voltage outputs. If a buck type LC filter was used to generate a high voltage, a very large inductance value would be needed to reduce the ripple current levels sufficiently to achieve the continuous mode operation required. This restriction does not apply to the flyback, since it does not require an output inductance for successful operation.

C. Disadvantages

From the flyback waveforms in Fig. 6 it is clear that the output capacitor is only supplied during the transistor off time. This means that the capacitor has to smooth a pulsating output current which has higher peak values than the continuous output current that would be produced in a forward converter, for example. In order to achieve low output ripple, very large output capacitors are needed, with very low equivalent series resistance (e.s.r). It can be shown that at the same frequency, an LC filter is approximately 8 times more effective at ripple reduction than a capacitor alone. Hence, flyback have inherently much higher output ripples than other topologies. This, together with the higher peak currents, large capacitors and transformers, limits the flyback to lower output power applications in the 20 to 200W range. (It should be noted that at higher voltages, the required output voltage ripple magnitudes are not normally as stringent, and this means that the e.s.r requirement and hence capacitor size will not be as large as expected.)

III. TWO TRANSISTOR FLYBACK

One possible solution to the 1000V transistor requirement is the two transistor flyback version shown in Fig. 7. Both transistors are switched simultaneously, and all waveforms are exactly the same, except that the voltage across each transistor never exceeds the input voltage. The clamp winding is now redundant, since the two clamp diodes act to return leakage energy to the input. Two 400 or 500V devices can now be selected, which will have faster switching and lower conduction losses. The output power and switching frequencies can thus be significantly increased. The drawbacks of the two transistor version are the extra cost and more complex isolated base drive needed for the top floating transistor.

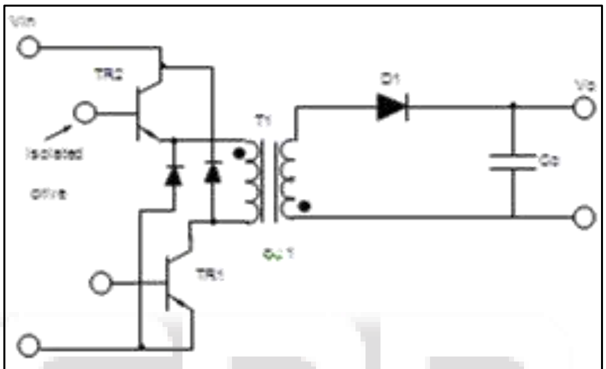

Fig. 7. Two transistor Flyback.

A. Continuous Vs Discontinuous operation

As with the buck-boost, the flyback can operate in both continuous and discontinuous modes. The waveforms in Fig. 6 show discontinuous mode operation. In discontinuous mode, the secondary current falls to zero in each switching period, and all of the energy is removed from the transformer. In continuous mode there is current flowing in the coupled inductor at all times, resulting in trapezoidal current waveforms.

The main plus of continuous mode is that the peak currents flowing are only half that of the discontinuous for the same output power, hence, lower output ripple is possible. However, the core size is about 2 to 4 times larger in continuous mode to achieve the increased inductance needed to reduce the peak currents to achieve continuity.

A further disadvantage of continuous mode is that the closed loop is far more difficult to control than the discontinuous mode flyback. (Continuous mode contains a right hand plane zero in its open loop frequency response, the discontinuous flyback does not. See Ref[2] for further explanation.) This means that much more time and effort is required for continuous mode to design the much more complicated compensation components needed to achieve stability.

There is negligible turn-on dissipation in the transistor in discontinuous mode, whereas this dissipation can be fairly high in continuous mode, especially when the additional effects of the output diode reverse recovery current, which only occurs in the continuous case, is included.

This normally means that a snubber must be added to protect the transistor against switch-on stresses.

One advantage of the continuous mode is that its open loop gain is independent of the output load i.e Vo only depends upon D and Vin as shown in the dc gain equation at the end of the section. Continuous mode has excellent open loop load regulation, i.e varying the output load will not affect Vo. Discontinuous mode, on the other-hand, does have a dependency on the output, expressed as RL in the dc gain equation. Hence, discontinuous mode has a much poorer open loop load regulation, i.e changing the output will affect Vo. This problem disappears, however, when the control loop is closed, and the load regulation problem is usually completely overcome.

The use of current mode control with discontinuous flyback (where both the primary current and output voltage are sensed and combined to control the duty cycle) produces a much improved overall loop regulation, requiring less closed loop gain.

Although the discontinuous mode has the major disadvantage of very high peak currents and a large output capacitor requirement, it is much easier to implement, and is by far the more common of the two methods used in present day designs.

Output power	50W		100W		200W	
Line voltage Vin	110V ac	220V ac	110V ac	220V ac	110V ac	220V ac
Transistor requirements Max current Max voltage	2.25A 400V	1.2A 800V	4A 400V	2.5A 800V	8A 400V	4.4A 800V
Bipolar transistors TO-220 Isolated SOT-186 SOT-93 Isolated SOT-199	BUT11 BUT11F – –	BUX85 BUX85F – –	BUT12 BUT12F – –	BUT11A BUT11AF – –	– – BUW13 BUW13F	BUT12A BUT12AF – –
Power MOSFET TO-220 Isolated SOT-186 SOT-93	BUK454-400B BUK444-400B –	BUK454-800A BUK444-800A –	BUK455-400B BUK445-400B –	BUK456-800A BUK446-800A –	– – BUK437-400B	– – BUK438-800A
Output Rectifiers O/P voltage 5V 10V	PBYR1635 PBYR10100 BYW29E-100/150/200		PBYR2535CT PBYR20100CT BYV79E-100/150/200		– PBYR30100PT BYV42E-100/150/200 BYV72E-100/150/200	
20V 50V 100V	PBYR10100 BYW29E-100/150/200 BYV29-300 BYV29-500		PBYR10100 BYW29E-100/150/200 BYV29-300 BYV29-500		PBYR20100CT BYV32E-100/150/200 BYV29-300 BYV29-500	

Table 2. Recommended Power Semiconductors for single-ended fly back.

B. The Forward converter

1) Operation

The forward converter is also a single switch isolated topology, and is shown in Fig. 8. This is based on the buck converter described earlier, with the addition of a transformer and another diode in the output circuit. The characteristic LC output filter is clearly present.

In contrast to the flyback, the forward converter has a true transformer action, where energy is transferred directly to the output through the inductor during the transistor on-time. It can be seen that the polarity of the secondary winding is opposite to that of the flyback, hence allowing direct current flow through blocking diode D1. During the on-time, the current flowing causes energy to be built up in the output inductor L1. When the transistor turns off, the secondary voltage reverses, D1 goes from conducting to blocking mode and the freewheel diode D2 then becomes forward biased and provides a path for the inductor current to continue to flow. This allows the energy stored in L1 to be released into the load during the transistor off time.

The forward converter is always operated in continuous mode (in this case the output inductor current), since this produces very low peak input and output currents and small ripple components. Going into discontinuous mode would greatly increase these values, as well as increasing the amount of switching noise generated. No destabilizing right hand plane zero occurs in the frequency response of the forward in continuous mode (as with the buck). See Ref[2]. This means that the control problems that existed with the continuous flyback are not present here. So there are no real advantages to be gained by using discontinuous mode operation for the forward converter.

C. Advantages

As can be seen from the waveforms in Fig. 8, the inductor current IL, which is also the output current, is always continuous. The magnitude of the ripple component, and hence the peak secondary current, depends upon the size of the output inductor. Therefore, the ripple can be made relatively small compared to the output current, with the peak current minimized. This low ripple, continuous output current is very easy to smooth, and so the requirements for Since the transformer in this topology transfers energy directly there is negligible stored energy in the core compared to the flyback. However, there is a small magnetization energy required to excite the core, allowing it to become an energy transfer medium. This energy is very small and only a very small primary magnetization current is needed.

This means that a high primary inductance is usually suitable, with no need for the core air gap required in the flyback. Standard un-gapped ferrite cores with high permeability (2000-3000) are ideal for providing the high inductance required. Negligible energy storage means that the forward converter transformer is considerably smaller than the fly back, and core loss is also much smaller for the same throughput power. However, the transformer is still operated asymmetrically, which means that power is only transferred during the switch on-time, and this poor utilization means the transformer is still far bigger than in the symmetrical types.

The transistors have the same voltage rating as the discontinuous flyback (see disadvantages), but the peak current required for the same output power is halved, and this can be seen in the equations given for the forward converter. This, coupled with the smaller transformer and output filter capacitor requirements means that the forward converter is suitable for use at higher output powers than the fly back can attain, and is normally designed to operate in the 100 to 400W range. Suitable bipolar and MOSFETs for the forward converter are listed in Table 3.

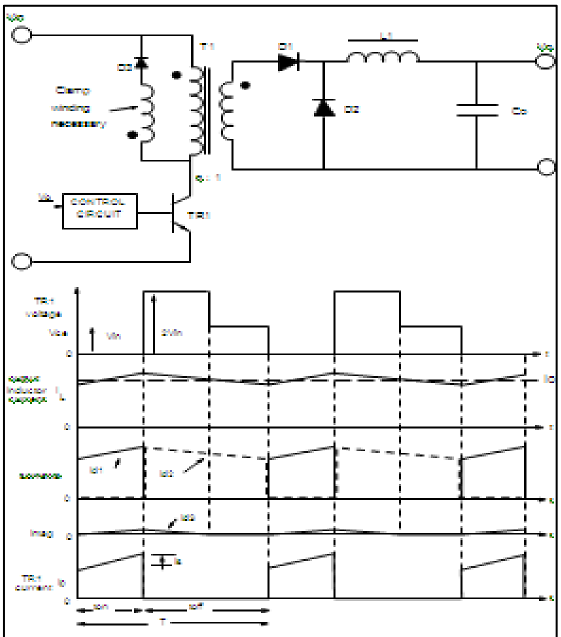

Fig. 8 The Forward converter and waveforms.

D. Disadvantages

Because of the unipolar switching action of the forward converter, there is a major problem in how to remove the core magnetization energy by the end of each switching cycle. If this did not happen, there would be a net dc flux build-up, leading to core saturation, and possible transistor destruction. This magnetization energy is removed automatically by the push-pull action of the symmetrical types. In the flyback this energy is dumped into the load at transistor turn-off. However, there is no such path in the forward circuit.

This path is provided by adding an additional reset winding of opposite polarity to the primary. A clamp diode is added, such that the magnetization energy is returned to the input supply during the transistor off time. The reset winding is wound bifilar with the primary to ensure good coupling, and is normally made to have the same number of turns as the primary. (The reset winding wire gauge can be very small, since it only has to conduct the small magnetization current.) The time for the magnetization energy to fall to zero is thus the same duration as the transistor on-time. This means that the maximum theoretical duty ratio of the forward converter is 0.5 and after taking into account switching delays, this falls to 0.45. This limited control range is one of the drawbacks of using the forward converter. The waveform of the magnetization current is also shown in Fig. 8. The clamp winding in the fly back is optional, but is always needed in the forward for correct operation.

Due to the presence of the reset winding, in order to maintain volt-sec balance within the transformer, the input voltage is back reflected to the primary from the clamp winding at transistor turn-off for the duration of the flow of the magnetization reset current through D3. (There is also a voltage reversal across the secondary winding, and this is why diode D1 is added to block this voltage from the output circuit.) This means that the transistor must block two times Vin during switch-off. The voltage returns to Vin after reset has finished, which means transistor turn-on losses will be smaller. The transistors must have the same added burden of the voltage rating of the fly back, i.e 400V for 110V mains and 800V for 220V mains applications.

IV. OUT-PUT DIODE SELECTION

The diodes in the output circuit both have to conduct the full magnitude of the output current. They are also subject to abrupt changes in current, causing a reverse recovery spike, particularly in the freewheel diode, D2. This spike can cause additional turn-on switching loss in the transistor, possibly causing device failure in the absence of snubbing. Thus, very high efficiency, fast trr diodes are required to minimize conduction losses and to reduce the reverse recovery spike. These requirements are met with Schottky diodes for outputs up to 20V, and fast recovery epitaxial diodes for higher voltage outputs. It is not normal for forward converter outputs to exceed 100V because of the need for a very large output choke, and fly backs are normally used. Usually, both rectifiers are included in a single package i.e a dual centre-tap arrangement. The Philips range of Schottkies and FREDs which meet these requirements are also included in Table 3.

A. Two Transistor Forward

In order to avoid the use of higher voltage transistors, the two transistor version of the forward can be used. This circuit, shown in Fig. 9, is very similar to the two transistor fly back and has the same advantages. The voltage across the transistor is again clamped to Vin, allowing the use of faster more efficient 400 or 500V devices for 220V mains applications. The magnetization reset is achieved through the two clamp diodes, permitting the removal of the clamp winding.

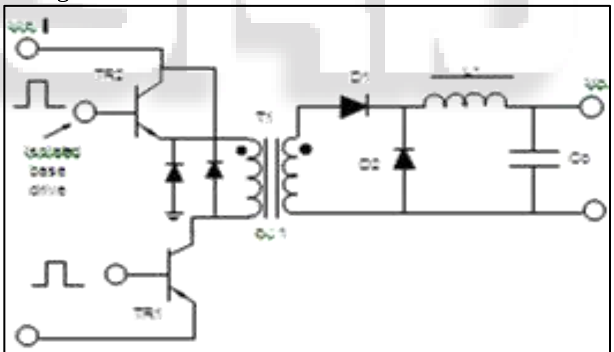

Fig. 9 Two transistor Forward.

The two transistor version is popular for off-line applications. It provides higher output powers and faster switching frequencies. The disadvantages are again the extra cost of the higher component count, and the need for an isolated drive for the top transistor.

Although this converter has some drawbacks, and utilizes the transformer poorly, it is a very popular selection for the power range mentioned above, and offers simple drive for the single switch and cheap component costs. Multiple output types are very common. The output inductors are normally wound on a single core, which has the effect of improving dynamic cross regulation, and if designed correctly also reduces the output ripple magnitudes even further. The major advantage of the forward converter is the very low output ripple that can be achieved for relatively small sized LC components. This means that forward converters are normally used to generate lower voltage, high current multiple outputs such as 5, 12, 15, 28V from mains off-line applications, where lower ripple specifications are normally specified for the outputs. The high peak currents that would occur if a fly back was used would place an impossible burden on the smoothing capacitor.

Output power	100W		200W		300W	
Line voltage, Vin	110V ac	220V ac	110V ac	220V ac	110V ac	220V ac
Transistor requirements Max current Max voltage	2.25A 400V	1.2A 800V	4A 400V	2.5A 800V	5A 400V	3.3A 800V
Bipolar transistors TO-220 Isolated SOT-186 SOT-93 Isolated SOT-199	BUT11 BUT11F – –	BUK85 BUK85F – –	BUT12 BUT12F – –	BUT11A BUT11AF – –	– – BUW13 BUW13F	BUT12A BUT12AF – –
Power MOSFET TO-220 Isolated SOT-186 SOT-93	BUK454-400B BUK444-400B –	BUK454-800A BUK444-800A –	BUK455-400B BUK445-400B –	BUK456-800A BUK446-800A –	– – BUK437-400B	– – BUK438-800A
Output Rectifiers (dual) O/P voltage 5V 10V 20V 50V	PBYR2535CT PBYR20100CT BYV32E-100/150/200 PBYR20100CT BYQ28E-100/150/200 BYT28-300		– PBYR30100PT BYV42E-100/150/200 BYV72E100/150/200 PBYR20100CT BYV32E-100/150/200 BYT28-300		– PBYR30100PT BYV72E-100/150/200 PBYR20100CT BYV32E-100/150/200 BYT28-300	

Table 3. Recommended Power Semiconductors for single-ended forward.

B. The Push-Pull Converter

1) Operation

To utilize the transformer flux swing fully, it is necessary to operate the core symmetrically as described earlier. This permits much smaller transformer sizes and provides higher output powers than possible with the single ended types. The symmetrical types always require an even number of transistor switches. One of the best known of the symmetrical types is the push-pull converter shown in Fig. 10.

The primary is a centre-tapped arrangement and each transistor switch is driven alternately, driving the transformer in both directions. The push-pull transformer is typically half the size of that for the single ended types, resulting in a more compact design. This push-pull action produces natural core resetting during each half cycle, hence no clamp winding is required. Power is transferred to the buck type output circuit during each transistor conduction period. The duty ratio of each switch is usually less than 0.45. This provides enough dead time to avoid transistor cross conduction. The power can now be transferred to the output for up to 90% of the switching period, hence allowing greater throughput power than with the single-ended types. The push-pull configuration is normally used for output powers in the 100 to 500W range.

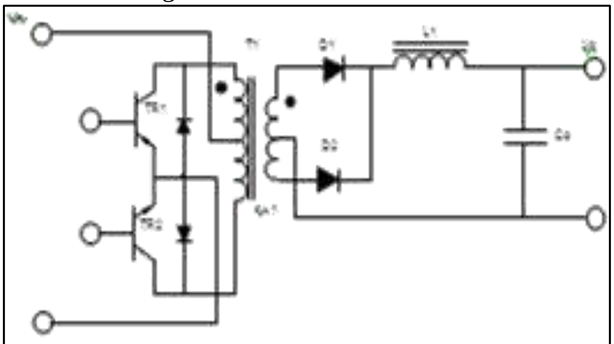

Fig. 10 Push-pull converter.

The bipolar switching action also means that the output circuit is actually operated at twice the switching frequency of the power transistors, as can be seen from the waveforms in Fig. 11. Therefore, the output inductor and capacitor can be even smaller for similar output ripple levels. Push-pull converters are thus excellent for high power density, low ripple outputs.

C. Advantages

As stated, the push-pull offers very compact design of the transformer and output filter, while producing very low output ripple. So if space is a premium issue, the push-pull could be suitable. The control of the push-pull is similar to the forward, in that it is again based on the continuous mode buck. When closing the feedback control loop, compensation is relatively easy. For multiple outputs, the same recommendations given for the forward converter apply.

Clamp diodes are fitted across the transistors, as shown. This allows leakage and magnetization energy to be simply channeled back to the supply, reducing stress on the switches and slightly improving efficiency.

The emitter or source of the power transistors are both at the same potential in the push-pull configuration, and are normally referenced to ground. This means that simple base drive can be used for both, and no costly isolating drive transformer is required. (This is not so for the bridge types which are discussed latter.)

D. Disadvantages

One of the main drawbacks of the push-pull converter is the fact that each transistor must block twice the input voltage due to the doubling effect of the centre-tapped primary, even though two transistors are used. This occurs when one transistor is off and the other is conducting. When both are off, each then blocks the supply voltage; this is shown in the waveforms in Fig. 11. This means that TWO expensive, less efficient 800 to 1000V transistors would be required for a 220V off-line application. A selection of transistors and rectifiers suitable for the push-pull used in off-line applications is given in Table 4.

A further major problem with the push-pull is that it is prone to flux symmetry imbalance. If the flux swing in each half cycle is not exactly symmetrical, the volt-sec will not balance and this will result in transformer saturation, particularly for high input voltages. Symmetry imbalance can be caused by different characteristics in the two transistors such as storage time in a bipolar and different on-state losses.

The centre-tap arrangement also means that extra copper is needed for the primary, and very good coupling between the two halves is necessary to minimize possible leakage spikes. It should also be noted that if snubbers are used to protect the transistors, the design must be very precise since each tends to interact with the other. This is true for all symmetrically driven converters.

These disadvantages usually dictate that the push-pull is normally operated at lower voltage inputs such as 12, 28 or 48V. DC-DC converters found in the automotive and telecommunication industries are often push-pull designs. At these voltage levels, transformer saturation is easier to avoid.

Since the push-pull is commonly operated with low dc voltages, a selection guide for suitable power MOSFETs is also included for 48 and 96V applications, seen in Table 5.

V. CURRENT MODE CONTROL

The introduction of current mode control circuits has also benefited the push-pull type. In this type of control, the primary current is monitored, and any imbalance which occurs is corrected on a cycle by cycle basis by varying the duty cycle immediately. Current mode control completely removes the symmetry imbalance problem, and the possibilities of saturation are minimized. This has meant that push-pull designs have become more popular in recent years, with some designers even using them in off-line applications.

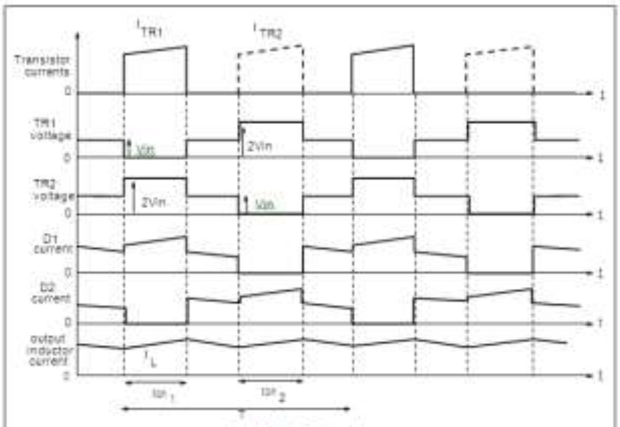

Fig. 11 Push Pull waveforms.

Output power	100W		300W		500W	
Line voltage, Vin	110V ac	220V ac	110V ac	220V ac	110V ac	220V ac
Transistor requirements Max current Max voltage	1.2A 400V	0.6A 800V	4.8A 400V	3.0A 800V	5.5A 400V	3.1A 800V
Bipolar transistors TO-220 Isolated SOT-186 SOT-93 Isolated SOT-199	BUT11 BUT11F — —	BUX85 BUX85F — —	BUT12 BUT12F — —	BUT11A BUT11AF — —	— — BUW13 BUW13F	BUT12A BUT12AF — —
Power MOSFET TO-220 Isolated SOT-186 SOT-93	BUK454-400B BUK444-400B —	BUK454-800A BUK444-800A —	BUK455-400B BUK445-400B —	BUK455-800A BUK445-800A —	— — BUK437-400B	— — BUK438-800A
Output Rectifiers (dual) O/P voltage 5V 10V 20V 50V	PBYR2535CT PBYR20100CT BYV32E-100/150/200 PBYR20100CT BYV32EB-100/150/200 BYT28-300		— PBYR30100PT BYV72E-100/150/200 PBYR20100CT BYV32E-100/150/200 BYT28-300		— — BYT230PI-200 PBYR30100PT BYV42E-100/150/200 BYV72E-100/150/200 BYT28A-300	

Table 4. Recommended Power Semiconductors for off-line Push-pull converter.

Output power	100W		200W		300W	
Line voltage, Vin	96V dc	48V dc	96V dc	48V dc	96V dc	48V dc
Power MOSFET TO-220 Isolated SOT-186 SOT-93	BUK455-400B BUK445-400B —	BUK454-200A BUK444-200A —	BUK457-400B BUK437-400B —	BUK456-200B BUK436-200B —	— — BUK437-400B	— — —

Table 5. Recommended power MOSFETs for lower input voltage push-pull.

VI. Conclusion

The most common S.M.P.S. converter topologies, the flyback, forward, push-pull, half-bridge and full-bridge types have been outlined. Each has its own particular operating characteristics and advantages, which makes it suited to particular applications.

The converter topology also defines the voltage and current requirements of the power transistors (either MOSFET or Bipolar). Simple equations and calculations used to outline the requirements of the transistors for each topology have been presented.

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