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MULTIPLE OUTPUT SMPS USING A SINGLE CUK CONVERTER

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ABSTRACT
Switched Mode Power supplies (SMPS) are used in large numbers to power up personal computers and many other consumer electronic appliances. Most of these appliances need multiple output power supplies of different current ratings and hence employ several DC/DC converters for output voltage regulation. Moreover, considering the large number of SMPS that are being used, the input power quality becomes a matter of concern. In this paper, a novel weighted error control approach has been proposed for a multiple output SMPS with improved input power quality so that all the outputs can be controlled using a **single** Cuk converter thereby improving the reliability and cost-effectiveness of the system. The proposed system has been designed and then the designed circuit has been simulated in PSIM environment. The results obtained show an excellent performance of the power supply in terms of its output voltage regulation and input power quality.

KEY WORDS
Switched Mode Power Supply (SMPS), Input power quality, output voltage regulation, multiple-output SMPS, Cuk Converter

1. Introduction

Most of the commercial and consumer products invariably require a switch mode power supply (SMPS) for powering up. The advent of power semiconductor devices and control techniques has enhanced the design aspects of SMPS that are normally employed in computers, space applications, medical electronics, communication equipments and consumer electronic appliances. When a high frequency link is used in an SMPS, it results in reduction in size and weight, low power losses and low manufacturing cost. Most of the SMPS use simple peak rectifying circuits because of their inherent ruggedness and simplicity. However, their input power factor is poor. Even small levels of harmonic distortion in the input current of an SMPS, when used in large numbers, cause a substantial distortion of AC waveform at input side. The effect of poor power quality is two fold: First, it adversely affects computers and other communication equipment causing malfunctioning and loss of data. Second, it may affect the electric utility by causing failure of power factor correction capacitors due to resonance condition, increased losses in cables, transformers and neutral wire conductors. Good power quality is very crucial on both the load side as well as supply side. Many of the consumer electronic products require an SMPS with multiple outputs. If there are ‘n’ regulated outputs, normally ‘n+1’ DC/DC converters are used. This increases the cost of the system and reduces the reliability. This paper addresses the design of a switching power supply with multiple isolated regulated outputs that are generated by a single Cuk converter with integrated magnetics. The control technique for regulating all the outputs is based on a weighted error approach.

2. Cuk converter based SMPS

Cuk converter is a DC/DC converter specially suited for SMPS applications [1-3]. A SEPIC-converter based multi-output SMPS has been reported in [4]. Though the Cuk converter uses more number of filter components as compared to the SEPIC converter, it offers a better solution for the problem of voltage regulation, especially for the multi-output power supply case, because of the possibility of magnetic coupling between the input and output inductors [5-7]. Due to this, the Cuk converter based topology is used in the present work.

To investigate the feasibility of using a Cuk converter with integrated magnetics in an SMPS, a single output 90W, +5V power supply has been designed and simulated first in the PSIM environment [8]. The basic single output SMPS using a Cuk converter is shown in Fig.1. The converter is operated in continuous conduction mode and has been designed to yield a regulated output of +5V. The design of the Cuk converter is done based on the equations provided in [9] and [10].

3. Control of Input current and Power Factor

The average current control technique has been used in this work for input current shaping and power factor correction as shown in Fig.2. The error in the output voltage is sensed and then passed through a PI controller to arrive at the required value of current from the converter. This current value is multiplied with the unity sinusoidal wave extracted from the sensing of input voltage from the mains. The input current is made to track this current waveform by making use of a hysteresis current controller. Thus the input current is forced to be a sinusoidal wave at unity power factor having required amplitude. This complete power factor correction circuit and current control loop have been modeled in PSIM environment for investigating their effectiveness.

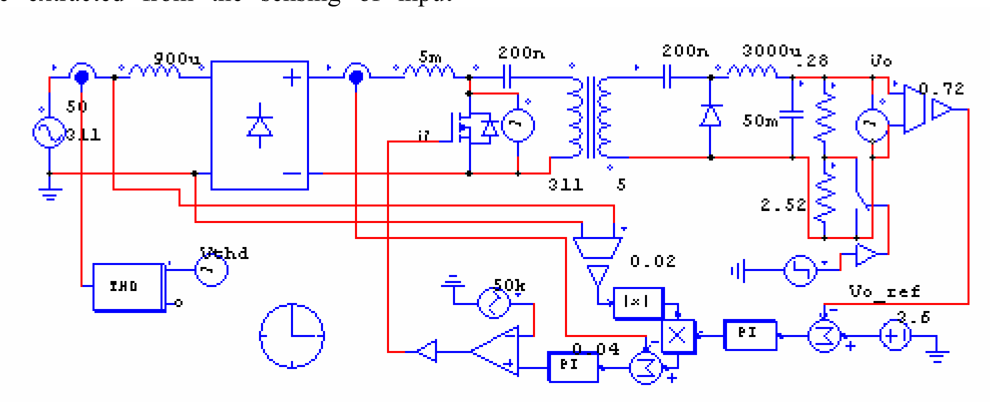


Fig.1 Cuk converter based single output SMPS

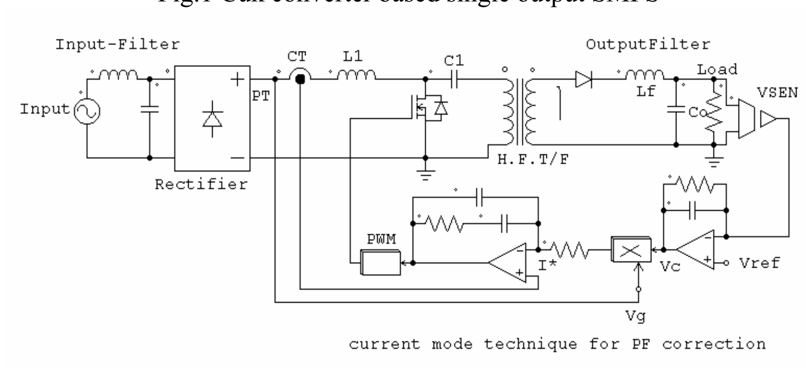


Fig.2 Input current shaping and PF control in SMPS

4. Simulation results of Single Output SMPS

The single output SMPS along with the input current shaping circuit has been designed and simulated in PSIM environment.

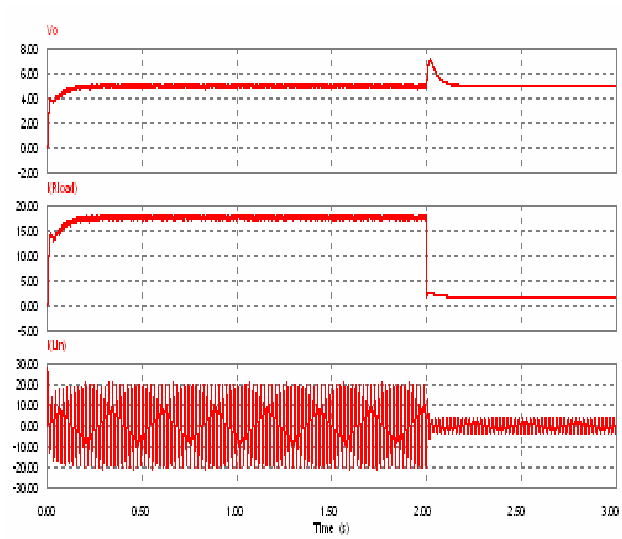


Fig.3 Response of the Cuk based single output SMPS under load perturbation

It can be seen from Fig.3 that the output stays regulated at +5 V irrespective of the load disturbances although a small increase in the voltage is seen at the time of throwing-off of the load. Subsequently, the voltage settles back to +5V. The start-up performance is also depicted in Fig.3. The ripple in the output voltage shown in Fig.4 shows that it is within a limit of ±2%. The input current is purely sinusoidal at unity power factor as can be seen from Fig.5. In Fig. 5 (a) & (b) the scales for voltage and current are 1000 V/div, 10 A/div and 500 V/div, 5 A/div respectively.

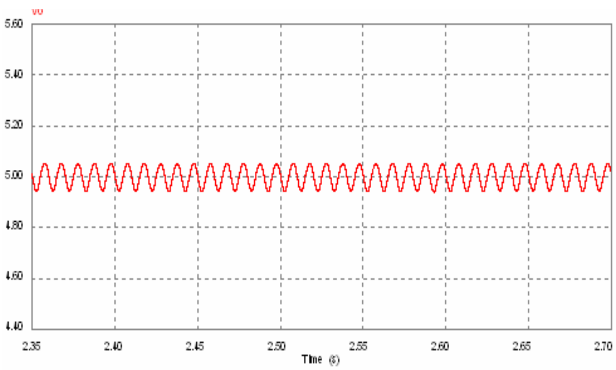
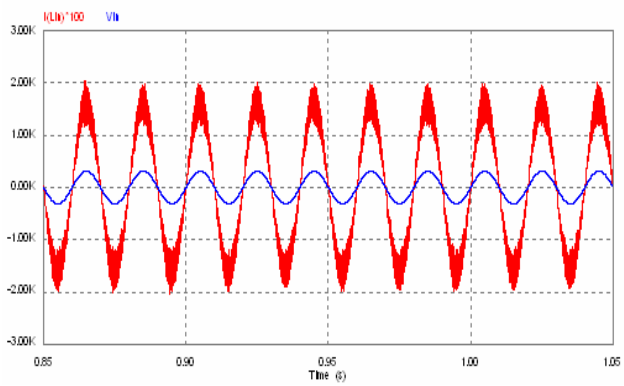
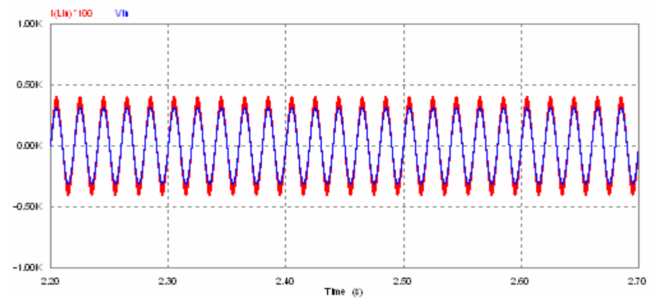


Fig.4 Output voltage ripple in the single output SMPS.



(a) At full-load



(b) At light load

Fig.5 Input voltage and current of the single output SMPS

5. Multiple output SMPS based on a single Cuk converter

As it has been mentioned in the introduction, an 'n' output SMPS uses normally 'n+1' DC-DC converters for obtaining regulated outputs. In this paper, it is proposed to use a single Cuk converter to obtain four regulated outputs. The specifications of the outputs are as follows:
+5 V, 18 A; -5V, 0.3 A ; +12 V, 6 A; -12 V, 0.8 A.
The circuit has been designed based on the equations given in [9]. The design has been done such that the output voltages obtained in open-loop are at the required levels when the power supplies are delivering full-load. To accommodate load changes as well as supply voltage variations and also to achieve good power quality at input end, closed loop control has been employed. For achieving closed loop control, two factors K_1 and K_2 are incorporated for each of these outputs. K_1 takes care of the significance of the capacity of a particular output with respect to the total rating of the power supply. K_{1n} is the ratio of the rating of the n^{th} supply to the total rating of the SMPS unit. K_2 takes care the load variations in individual supplies. K_{2n} is the ratio of the load on the n^{th} power supply at present to the actual rating of that particular supply.

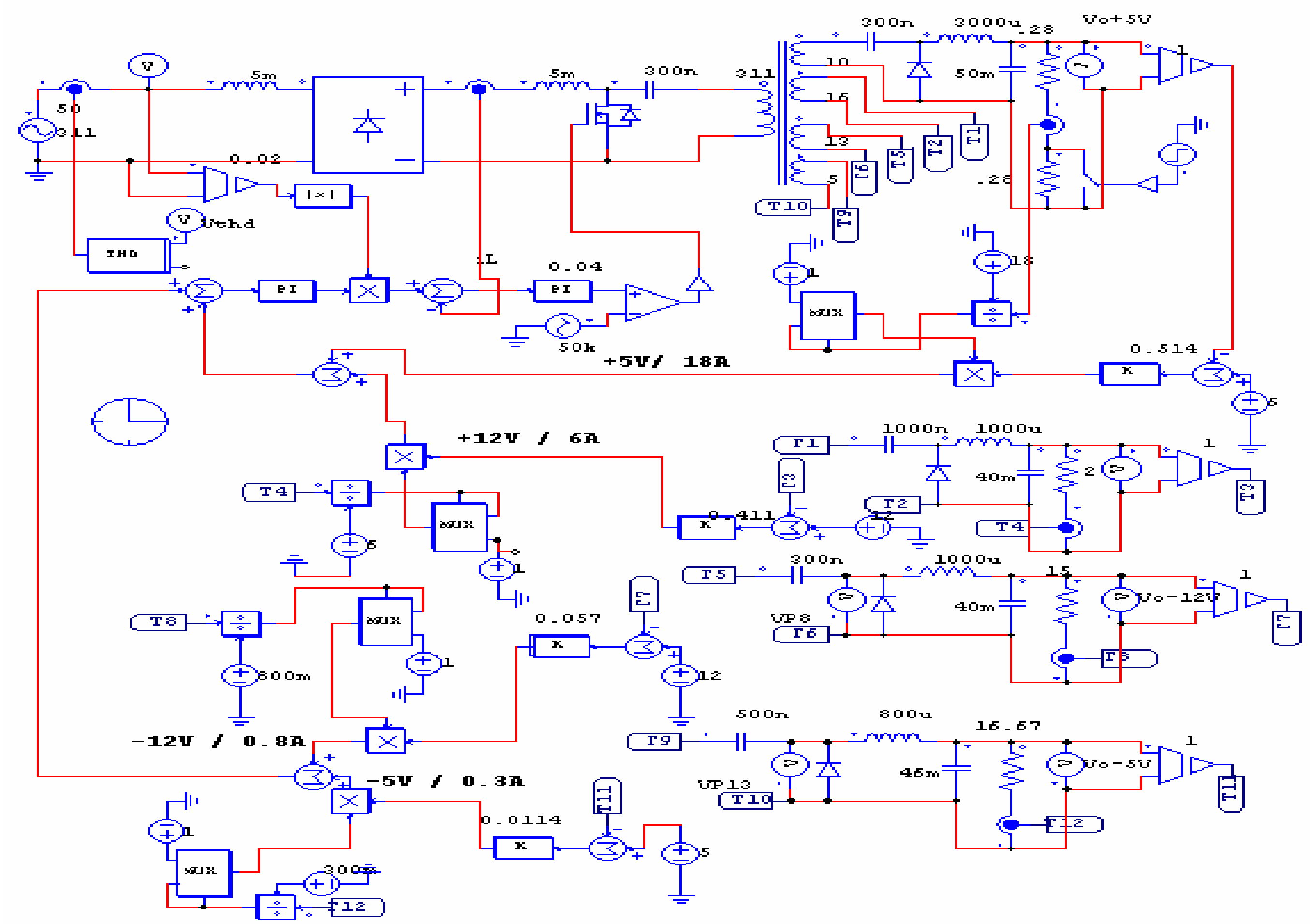


Fig.6 Control scheme for the multiple output SMPS based on single Cuk converter

The output voltage error from each of the power supplies is passed through their respective K_1 and K_2 factors and summed up to obtain the reference current magnitude. Further, this current is multiplied with the unity amplitude sine wave obtained from the mains voltage to generate the reference current waveform. Subsequently, a hysteresis controller is employed to develop the switching pattern for the device in the Cuk converter so that the input current is a unity PF sinusoidal wave.

The multiple output SMPS along with the control configuration is shown in Fig.6. The basic working and design aspects of a single Cuk converter based multiple output SMPS have been given in [9] and [10].

6. Simulation results of multiple output SMPS

The multiple output SMPS as described above has been designed and simulated in the PSIM environment and the simulation results obtained have been presented below with the control loop in place:

The start-up time of this power supply is found to be less than 0.1 sec. All the outputs settle down to their respective values with the ripple being less than 2%. When a load disturbance is given in +5 V supply at 0.51sec (from 20% to 90% load), although there is a little dip in the output voltages, the outputs bounce back to their original regulated values within 0.02 sec. The output voltage responses are shown in Fig.7.

Fig.8 shows the input voltage and current during light load and full-load conditions. In both the cases the THD of the input current is falling within 5%, which is very much within IEEE-519 standards [11]. The performance parameters of the multiple output power supply are tabulated in Table 1.

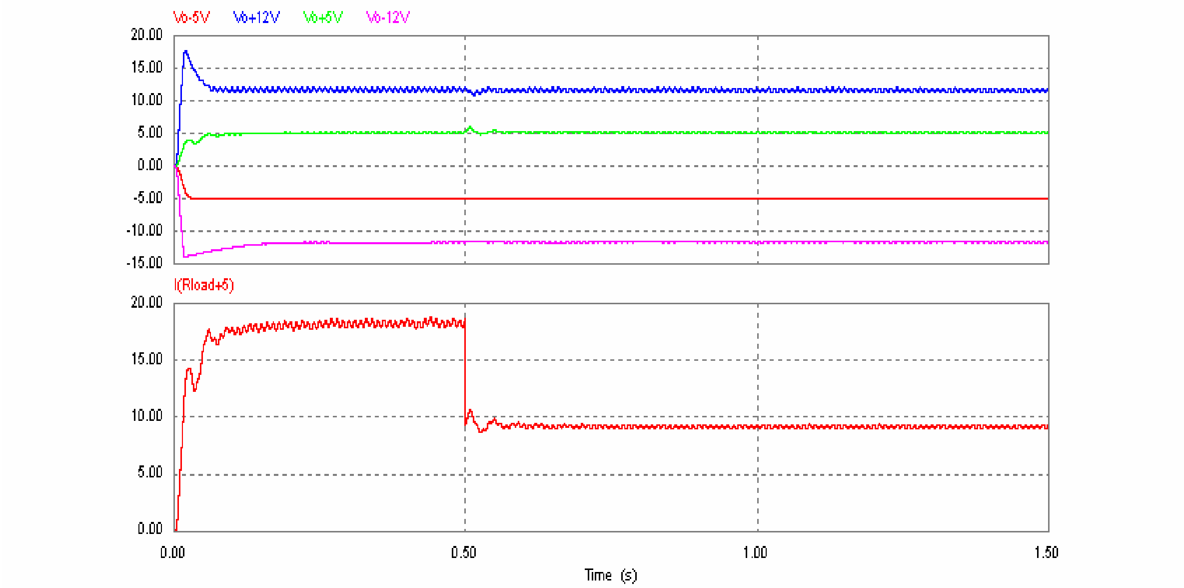
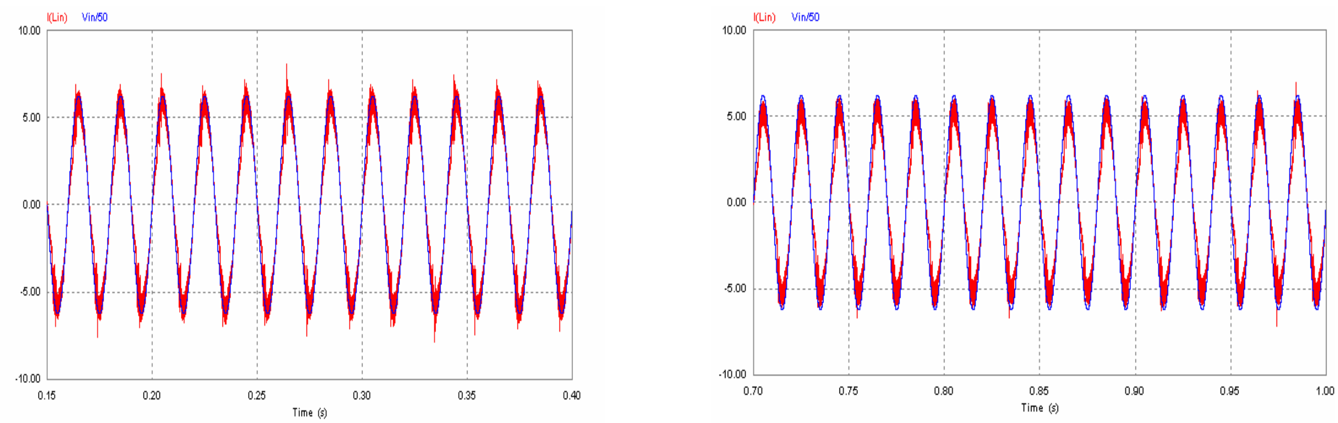


Fig.7 Output voltage response of the multiple output power supply during start-up and load disturbance



(a) Full-load (b) Light load

Fig.8 Input current and voltage waveforms of the multiple output SMPS

Table 1. Multiple output SMPS-Performance parameters

Power Supply specification	**Output Voltage Ripple-on load**		**Output Voltage Regulation-on load**		Input Current THD on load		Input Power Factor on load	
	100%	50%	100%	50%	100%	50%	100%	50%
+12V/6A	5.18%	4.71%	2.591%	2.355%	3.116	3.230	0.9947	0.9917
+5V/18A	3.994%	4.285%	1.997%	2.142%				
-12V/0.8A	1.54%	1.039%	0.770%	0.519%				
-5V/0.3A	1.016%	0.768%	0.508%	0.327%				

7. Conclusion

This paper presents the design and simulation of an improved power quality SMPS based on a single Cuk converter with multiple regulated outputs. The control loop employed uses a weighted average of errors obtained from the various outputs. The weightage of each of the individual supply is decided based upon its rating and the load it is carrying at a given instant. The entire system has been designed and simulated in PSIM environment. The response of the system has been obtained during start-up and also during load perturbations. The system is found to perform very well under these dynamic operating conditions. In all, this paper proposes a novel control methodology for a multiple output SMPS using a single Cuk converter thereby improving the reliability and cost-effectiveness of the system.

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