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Optimizing Efficiency On Conventional Transformer Based Low Power AC/DC Standby Power Supplies

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ABSTRACT

This article describes the research results for simple and cheap methods to reduce the idle- and load-losses in very low power conventional transformer based power supplies intended for standby usage. In this case "very low power" means 50Hz/230V-AC to 5V-DC@1W. The efficiency is measured on two common power supply topologies designed for this power level.

The two described topologies uses either a series (or linear) or a buck regulation approach. Common to the test power supplies is they either are using a standard cheap off-the-shelf transformer, or one, which are loss optimized by very simple means.

INTRODUCTION

This paper cover a selection of the research work which was performed to support the standby power supply project [1,2], [4-7], which was is a cooperative project between the Technical University of Denmark [3] and a number of industrial partners [8].

When power supplies designed for very low output power (0.25 - 5W) there is normally no or only less attention to the size of the no-load loss and load dependent losses. The attention is usually only on how cheap or how small it is. If the small power supplies is intended for some sort of standby purposes, these losses is becoming an very important issue.

Why?, The majority of the standby power supplies is usually always left connected to the mains, which means they are consuming power due to losses.

The yearly amount of wasted power in common domestic equipment's is often much larger than imagined. In Denmark each continual consumed Watt/year causes approximately \$2 yearly unwanted extra expense for the average domestic user. As more and more domestic appliances contains some sort of standby power supplies the idle loss issue has become more and more important.

Analyses from [4] indicated that 10-15% of the overall domestic power is consumed by unwanted idle losses in domestic equipment's which always are connected to the mains.

A typical and well designed small power supply, which can provide 1W of useful output power at 5V-DC often have an internal loss above 3W (typically it's in the range of 3-6W). The comparably large internal power losses means that the overall AC-to-DC conversion efficiency is very low.

Because of this fact, it's an obvious issue to research in any preferable simple possibilities to improve it - as to presented in this paper, without the use of any special technology. It is interesting issue to determine how much the efficiency can be improved by the use of simple and cheap conventional technology. The term conventional is used for a power supply which uses a common 50Hz transformer with a sheet iron core to provide the galvanic insulation and voltage transformation. Another interest is to determine were the dominant power losses is, how to reduce them and how much.

DISCUSSION

This research work covers traceable high precision experimental measurements on two common power supply regulation topologies:

- Series regulated topology
- Buck regulated topology

DC-voltage on the large charge capacitor figure 1 after the transformer and rectifier, is determined by the mains voltage and the transformer transfer-ratio "n". The DC-voltage on the charge capacitor must always be equal to or larger the required output voltage. It has also to be taken into account, that the mains input voltage newer is completely stable, usually is specified to -10% and to +6% of the 230V-AC, but in real world a additional headroom must be added, maybe an extra $\pm 20\%$. Furthermore some ripple-voltage must be accepted to keep the capacitor at a reasonable value. The purpose of the regulator between the charge capacitor and the output, is to keep the output voltage stable under all the mentioned conditions.

The first mentioned regulation method (figure 2) which most likely is used in today's equipment's, uses a series or linear regulator, which is a dissipative regulator. This means that the voltage difference between charge capacitor and the output is subtracted by the series regulator. The loss will be equal $(U_{\text{charge}} - U_{\text{out}}) \cdot I_o$. Even at the best possible design, in this case with $U_{\text{out}} = 5V$, the loss is theoretically at least two times the useful output power. This means that efficiency is less than 33%.

The second mentioned regulation method (figure 3) uses a very simple switch-mode regulator which at least in the theory is loss less. In the real world it will have an efficiency around 80% @ 5V output voltage. This means the excessive voltage on the charge capacitor not is subtracted in a dissipative way. As an result this

approach have a much lower load dependent loss than first method.

The two test regulators (series and buck) is built with cheap components. Any used IC's/Voltage reference's are low power, but still cheap of-the-shelf parts. The buck regulator uses a $f_{\text{sw}} = 30\text{kHz}$.

To make the comparison reasonable, two optimal chosen off-the-shelf transformers is selected. To optimize the overall efficiency, two optimal chosen and special designed (best output voltage and low no-load losses) transformers is also selected. The mentioned special designed transformer's are optimized in a way so they still are comparably cheap. More information can be found in [6].

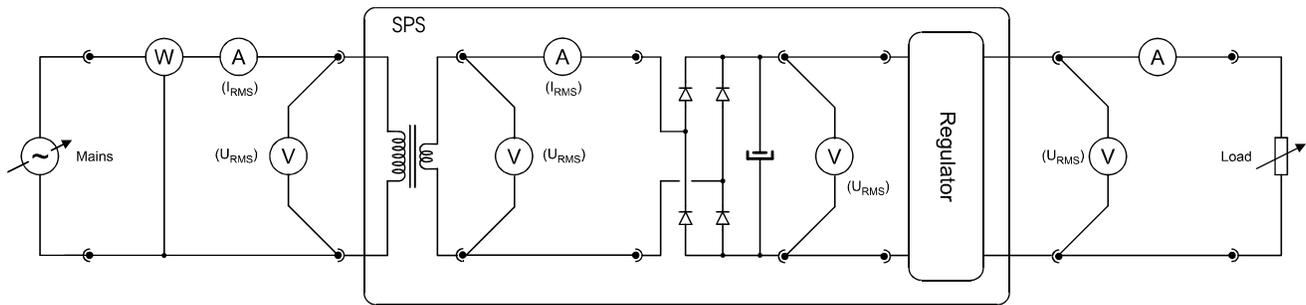


Figure 1 The full block diagram used when measuring the power supply efficiency

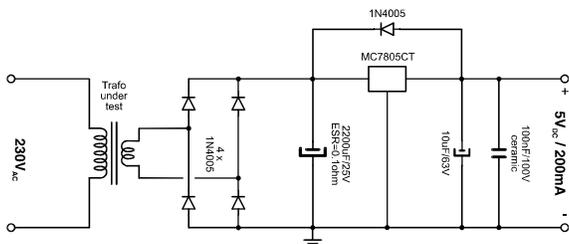


Figure 2 Test circuit for the series regulated power supply

Basically the research work with the conventional power supply reference data measurements, is intended to form an solid comparison data base for any new power supply designs for very low power 230V-AC to 5V-DC@1W. As an example power supplies created by using e.g. mains operated switch mode topologies [2].

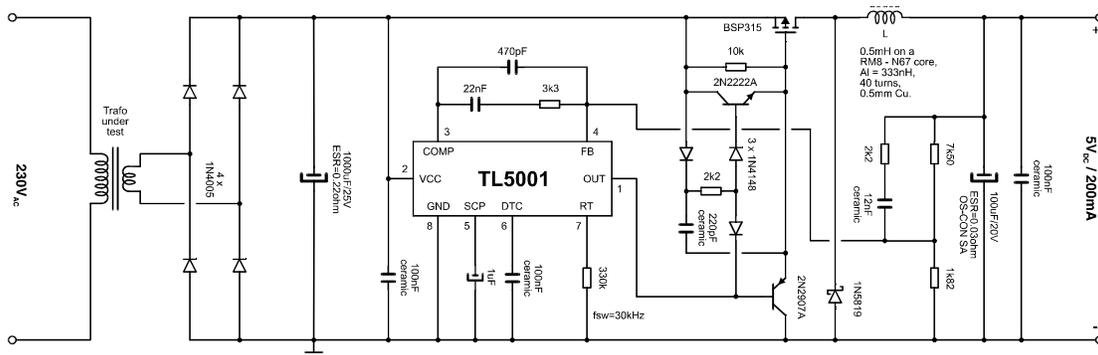


Figure 3 Test circuit for the buck regulated power supply

The Experimental Load Measurements

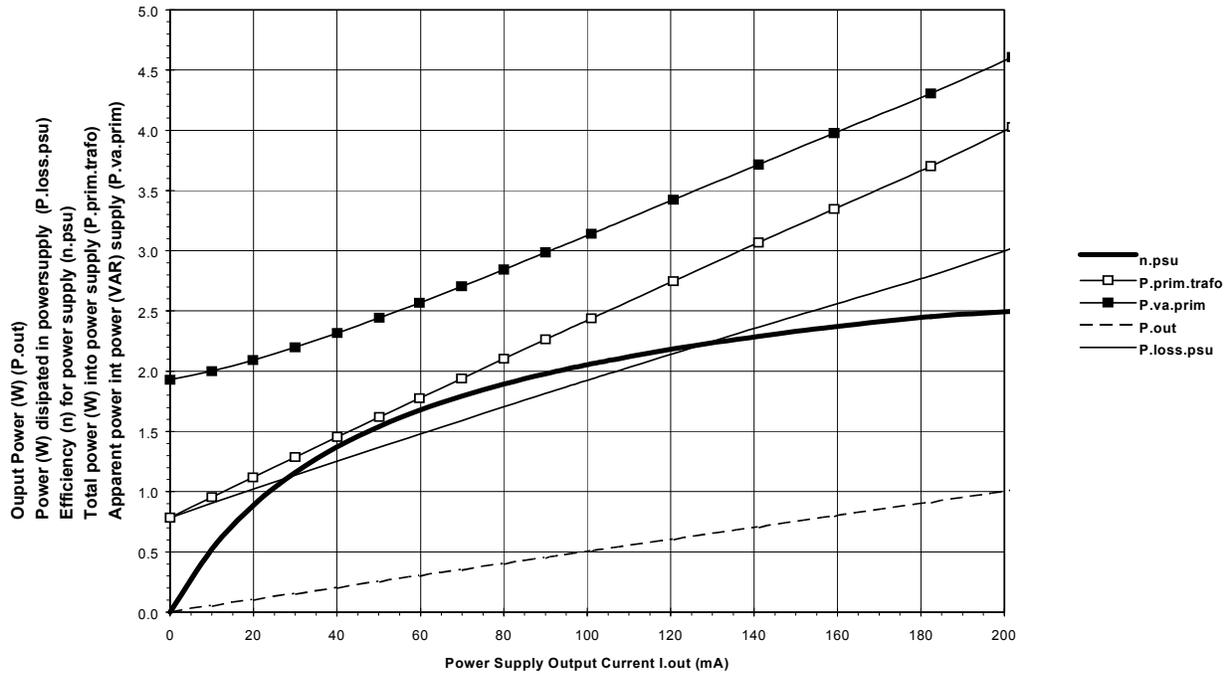


Figure 4 Efficiency for the series regulated topology using an off-the-shelf transformer (DT1020001)

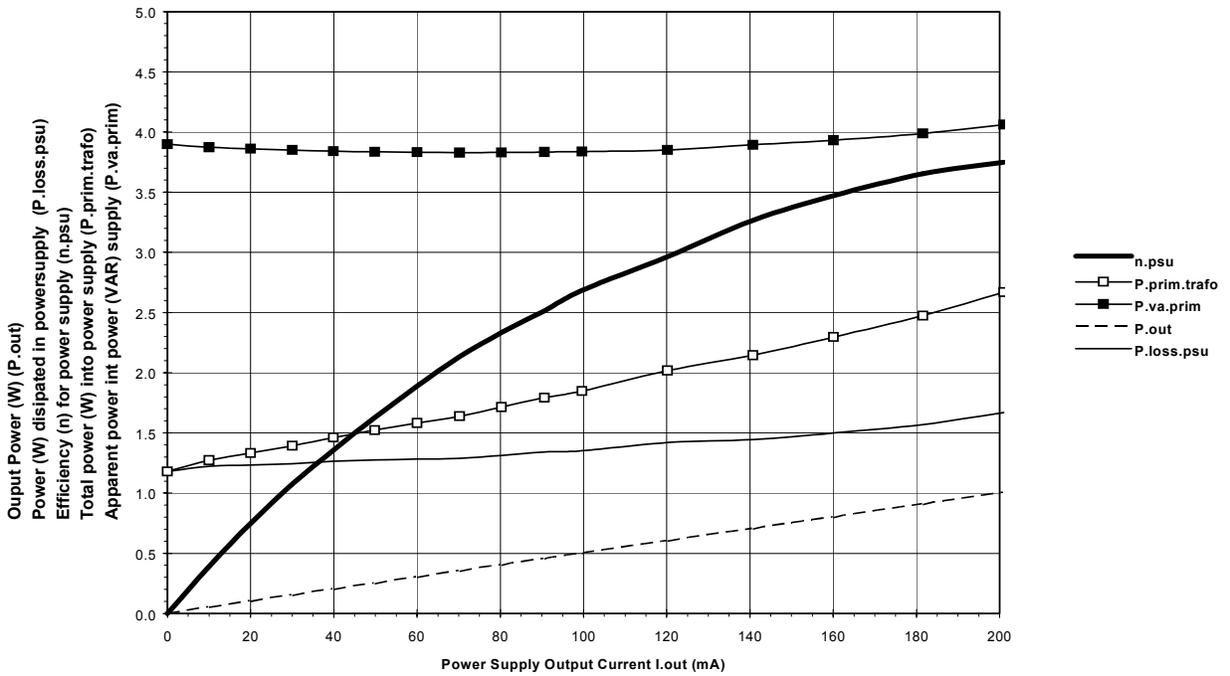


Figure 5 Efficiency for the buck regulated topology using an off-the-shelf transformer (DT1010101)

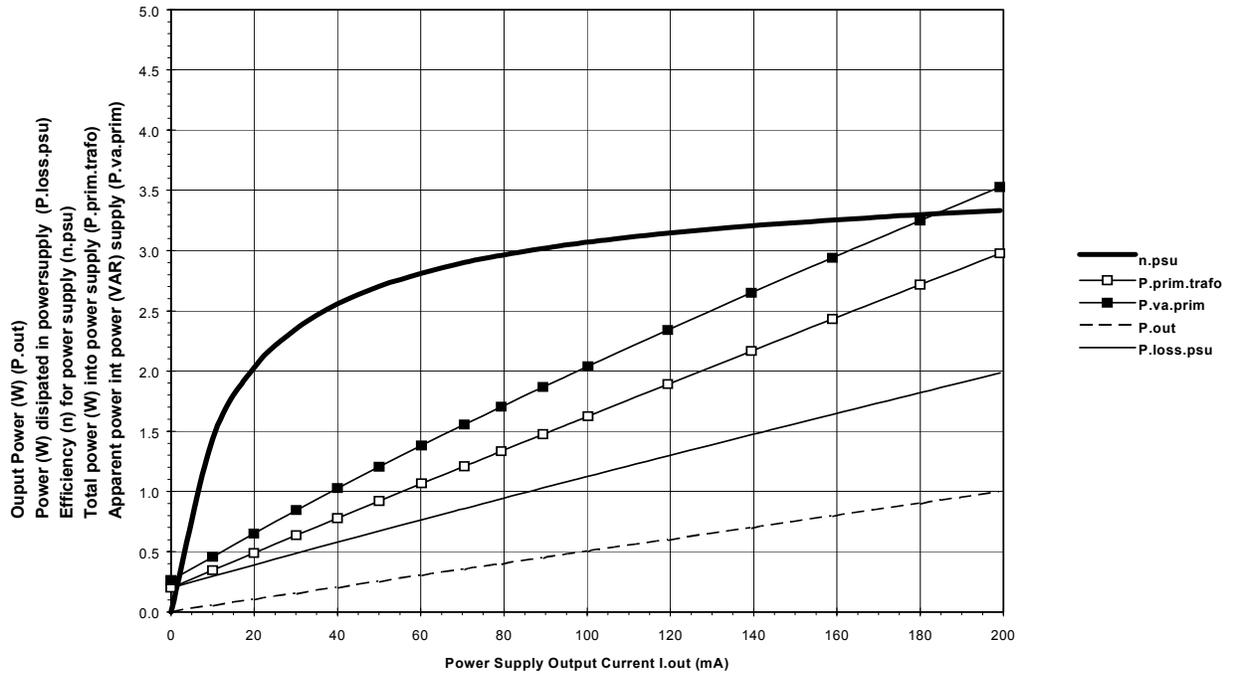


Figure 6 Efficiency for the series regulated topology using an optimized transformer (B075W10A)

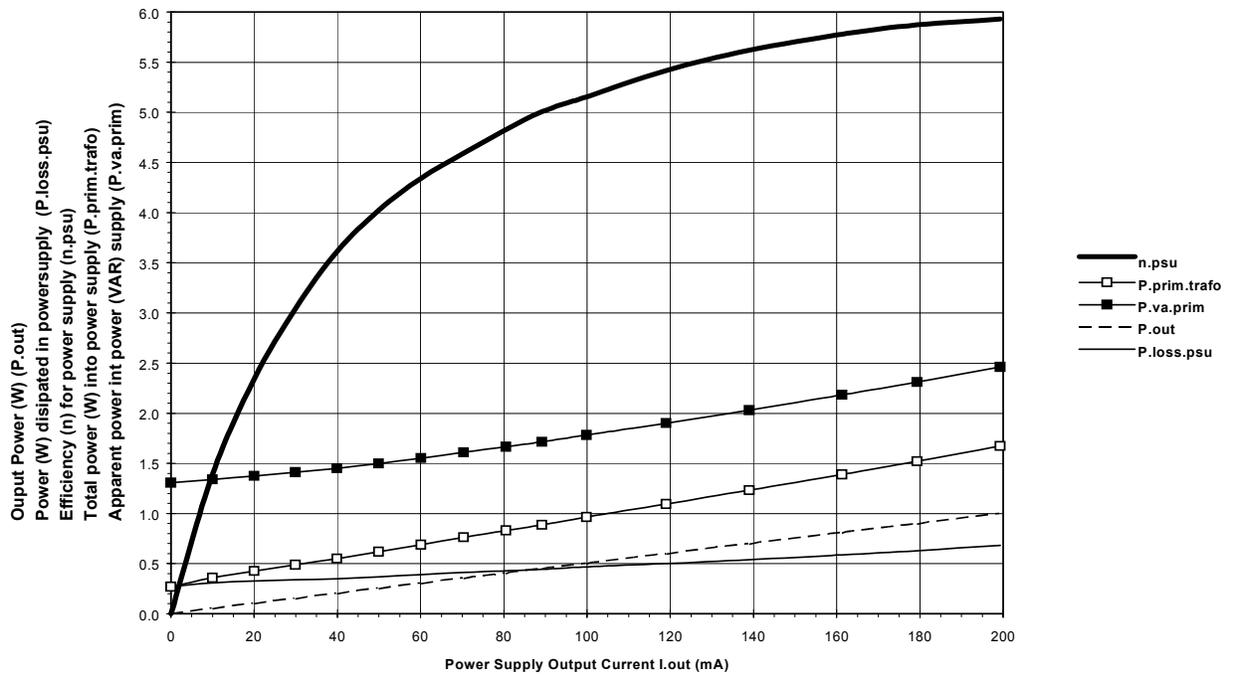


Figure 7 Efficiency for the buck regulated topology using an optimized transformer (B075W10)

THE FINAL RESULTS

All measurements is made with as high accuracy as possible. The most raw measurements is made with 0.1% accuracy. The overall target accuracy is $\pm 1\%$ or better. The primary voltage (230V-AC $\pm 1V$) is provided by a controlled sinus voltage source (Hewlett Packard HP6843A) and the input power is measured by a power analyzer (Voltech PM3000A) and the currents and voltages is measured by precision instruments (Hewlett Packard HP34401A). All the relevant measurements is performed as 4-wire configuration. Figure 1 shows the full measurement block diagram. The measurements performed on the off-the-shelf and the optimized transformer based series regulated topology based power supply is shown as figure 2. Also the measurements for the off-the-shelf and the optimized transformer based buck-regulated topology based power supply is shown as figure 3. For comparison the electronic circuit is equal for both standard and the optimized transformer.

The results for the series regulator approach is shown on figure 4 (using a off-the-shelf transformer) and 6 (using a optimized transformer).

Results for the buck regulated approach is shown on figure 5 (using a off-the-shelf transformer) and on figure 7 (using an optimized transformer). Please remark that the Y-axis is different compared to the other plot-figures due to the higher obtained efficiency.

	Series-reg. Off-the-s.	Series-reg. Optimized	Buck-reg. Off-the-s.	Buck-reg. Optimized
Transformer	DT1020001	B075W10A	DT1010101	B075W10
Idle Loss	785mW	201mW	1179mW	271mW
Full load loss	3.022W	1.985W	1.669W	0.6815W
η @ $I_o=10mA$	5%	14%	4%	14%
η @ $I_o=100mA$	21%	31%	27%	52%
η @ $I_o=200mA$	25%	33%	37%	59%

Table 1 Efficiency comparisons highlights at 230V-AC

CONCLUSION

The research confirms that the losses can be reduced remarkably in a conventional low power, power supply using a standard 50Hz transformer.

The research work shows in particular it's the transformers no-load loss which can be greatly reduced. The overall losses can be reduced the most by using an loss optimized 50Hz transformer together with an buck based switch mode regulated topology, instead of the usual series- or linear-regulation principle.

By the use of an loss optimized transformer and the buck regulated topology, the overall idle losses is reduced about three times. Full-load efficiency is improved to more than twice the value that can be obtained by the simple series regulator with an off-the-shelf transformer. By using the described optimized power supply which is optimized by simple means compared to the optimal designed one the domestic energy budget improvement is in the range of \$2 to \$5 per year depending on the usage pattern.

This may not sound of much, but the real world low power supplies often performs much worse than the one referenced to, which still is a optimal design but with off-the-shelf component (it doesn't say anything about the losses in cheap and dirty components). Furthermore it must be remembered the these small power supplies is embedded in nearly every new appliances today, often ten or more per household.

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