УДК 621.311.6

SECONDARY POWER SUPPLIES: ANATOMY AND APPLICATION

V. Gurevich
Honorable professor Central Electric Laboratory, Israel Electric Corp.
e-mail: vladimir.gurevich@gmx.net

In this paper design and characteristics of linear (LPS) and switching mode (SMPS) power supplies are described and comparison between them is performs. It is shown, that often SMPS have unfairly complex structure, very high density of elements and they are less reliable than LPS. It is offered to use automatic, protection and the control devices which installed in cabinets without the built in power supplies. For a feeding of all these devices it is offered to use in cabinet only two common linear power supplies: basic and reserve

***Keywords**: linear power supply, switching mode power supply, power factor correction, pulse-width modulation, buster converter*

The power supply is the principal component of any electronic device upon which the reliability of the device's working capacity depends.

In the 1960's the first Switch-Mode Power Supply (SMPS) was brought out. And since then has been intensively developed until today the SMPS has almost completely eclipsed the older Linear Power Supply (LPS) from all areas of technology. What is the difference between these two types of the secondary power supplies and is SMPS superior to the LPS?

Widely applied everywhere in technical equipment during many decades the LPS are rather simple and even primitive devices, Fig. 1, consisting of only a few elements: a voltage transformer, the rectifier, a filter based on a capacitor, and a semi-conductor stabilizer (the Zener diode with the powerful transistor, or a single power solid state element with an analogous function).

Unlike the LPS the SMPS are much more complex devices working at high frequency and consisting of hundreds of active and passive elements, Fig. 2.

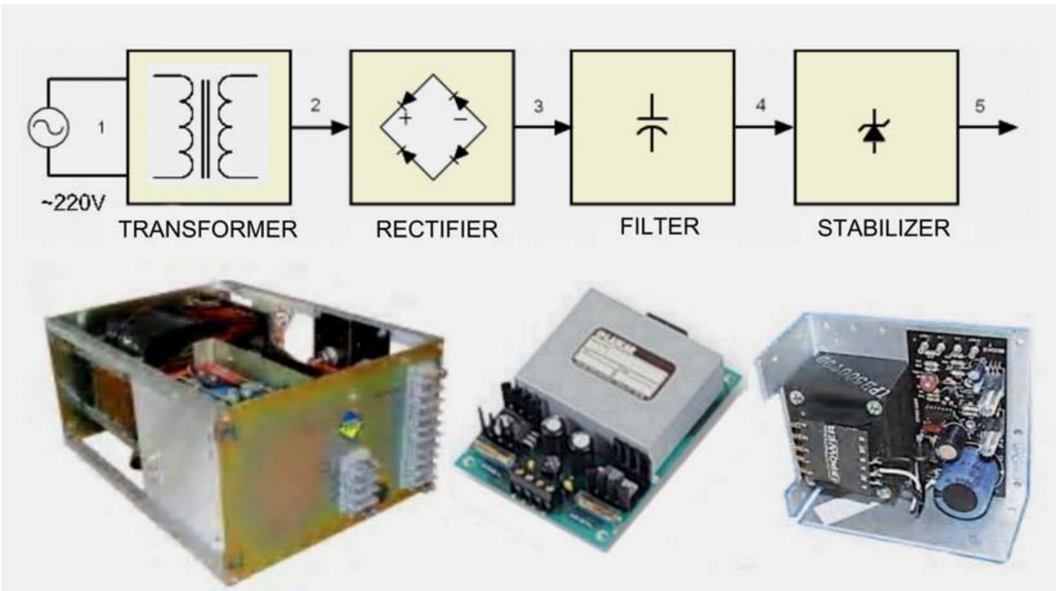

Fig. 1. Structure and appearance of linear power supplies

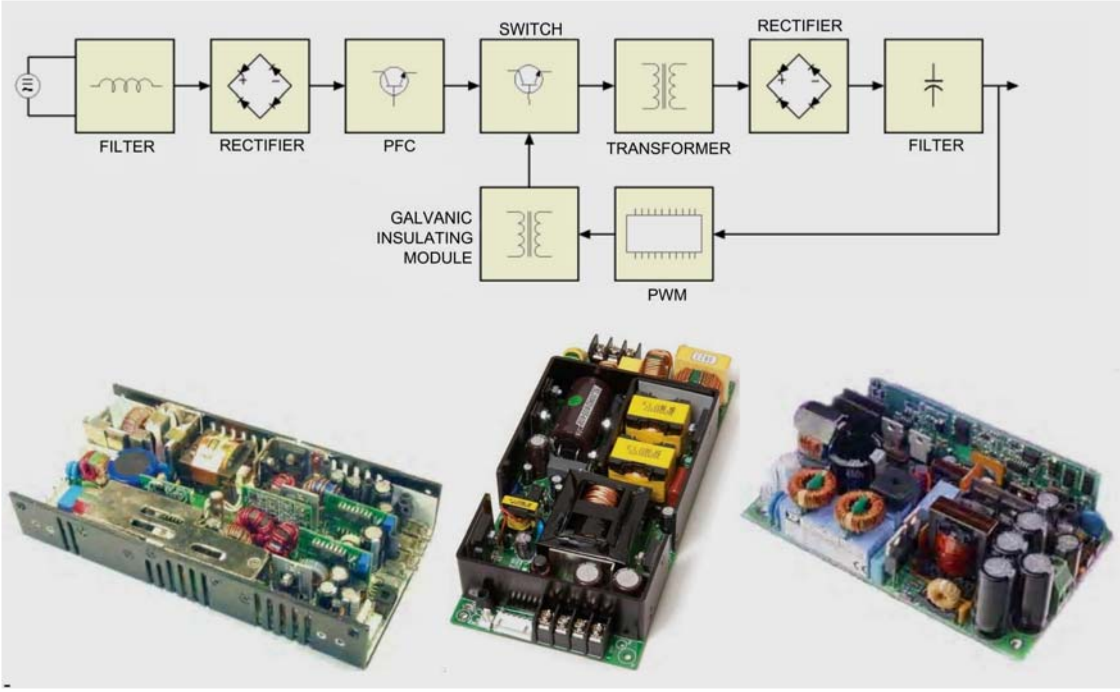

Fig. 2. Structure and appearance of switching mode power supplies

What are the basic differences between these two types of power supplies? In LPS the input alternating voltage is transformed to a necessary level (or levels, in the case of multiple secondary windings in the transformer) by means of the transformer, then rectified by a diode bridge, filtered by means of the electrolytic capacitor and stabilized by a nonlinear electronic element. The voltage applied to the stabilizing element must be greater than the nominal output voltage of the power supply, and its excess is dissipated in the form of heat on this stabilizing element (this sometimes demands use of heat sink).

The presence of some excess of a voltage on the stabilizing element enables carrying out stabilization of an output voltage with decreased or increased input voltage due to change of the share of the energy dissipation on the stabilizing element. For this reason, the coefficient of efficiency of such power supplies is always much more below one.

In the SMPS the input alternating voltage is first of all rectified by a diode bridge (or simply passed through the diodes of this bridge without change in the case of feeding a secondary power supply from a DC network). Then it is smoothed out and acts on the switching element (usually based on MOSFET transistor) by means of which the constant voltage "is cut" into narrow strips (switching frequency is from 70 up to 700 kHz for high power supplies and from 1 to 3 MHz for low-power supplies). The rectangular high-frequency pulses that are generated are applied to the transformer which outputs voltage matching the demanded level of a voltage which then is rectified and smoothed. The stabilization of the level of the output voltage at changes of the level of the input voltage is carried out by means of a feedback circuit consisting of a special driver which provides a pulse-width modulation (PWM) control signal of the switching element through of a galvanic decoupling unit (it is usual to include an additional isolation transformer). This driver is small, but contains a complex integral circuit to change the width of control pulses according to power supply output voltage level in order to compensate for deviations.

Low-cost power supplies have such structures. Better and more expensive SMPS devices contain, at least, two additional units: the input high-frequency filter and the Power Factor Corrector (PFC), Fig. 2. First unit is necessary for protection of the network, that is, all other consumers connected to same network that SMPS, from the high-frequency harmonics oscillated into the network by the SMPS. Second unit is used to increase a power factor of the power supply. The problem of the correction of a power factor (PF) originates due to the presence of the rectifier bridge with the smoothing capacitor on SMPS input. In such a circuit the capacitor consumes a current, by pulses, from a network only during those moments of time when an instantaneous value of the input sinusoidal voltage becomes more than the DC voltage on the capacitor (which depends on that discarded from the load). During the rest of the time when the voltage on the capacitor is more than the instantaneous input value, diodes of a rectifier bridge appear locked by a reverse voltage applied from the capacitor and consumption of a current is absent. As a result, the current consumed by the SMPS appears essentially out of voltage phase, Fig. 3a.

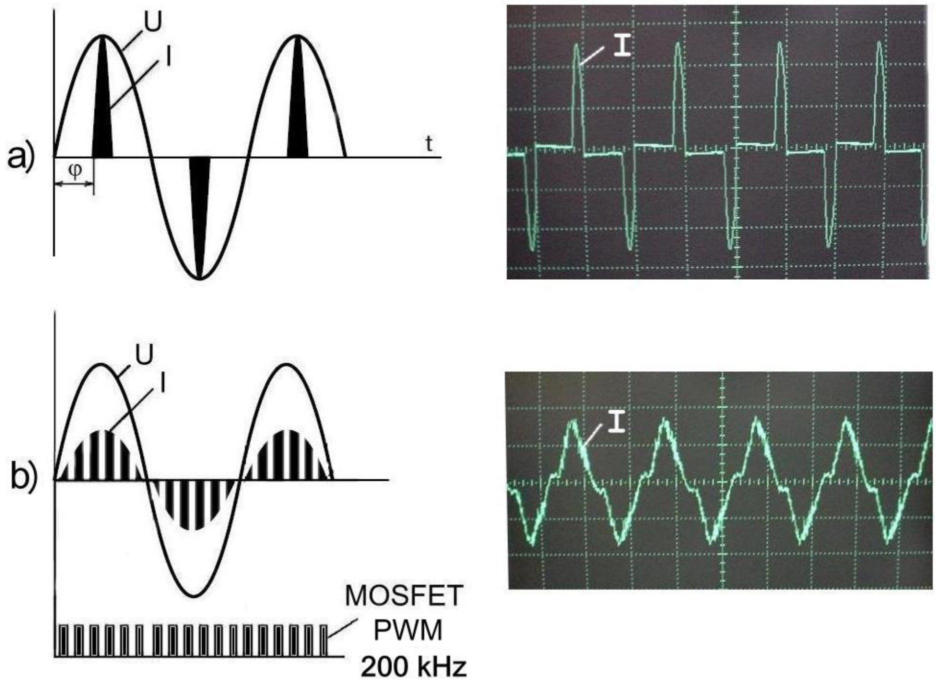

Fig. 3. The form of a current and shift of phases between a voltage and a current consumed SMPS, without PFK (a) and with PFC (b).

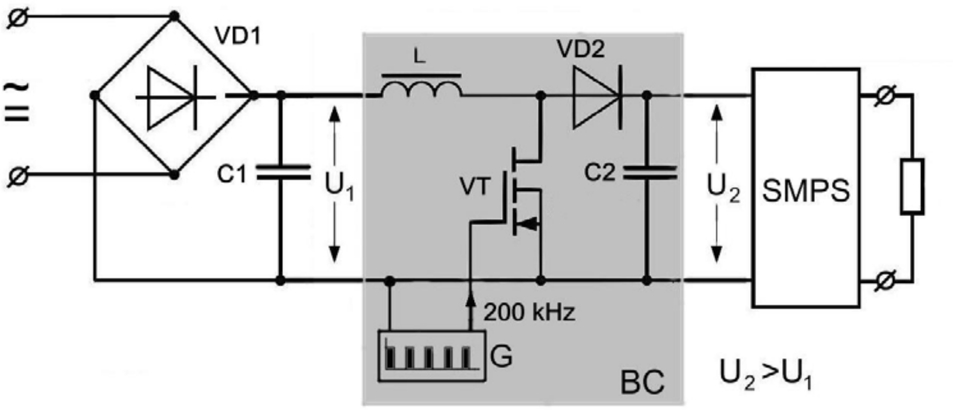

Fig. 4. Connections diagram the buster converter (BC) with the SMPS.

When a great number of SMPS devices are connected to an AC network, the combined decrease of the PF in the network becomes appreciable (typical PF values for a single SMPS without correction is 0.65). In this connection active PF correction is employed by means of the so-called Power Factor Corrector (PFC) in the SMPS.

PFC is an independent voltage converter, the so-called “boost converter” (BC), supplied with the special control circuit, Fig. 4.

Basic elements of the BC are: choke L, diode VD2, capacitor C2 and fast switching element VT (based on a MOSFET transistor). The functioning of this device is based on the production of an high voltage pulse with a reversed polarity on the inductance (L) at the breaking of a current in its circuit. Transistor VT switches the current in the inductance, L, on and off at a high frequency (it is usually 200 kHz), and the high voltage pulses formed during the switching process charge the capacitor C2 through diode VD2 from which the load (in our case, actually, the SMPS) feeds. Thus, a voltage on the capacitor C2 always exceeds the input BC voltage. Owing to this property, the BC is widely used in electronic devices as the voltage level converter: from the standard voltaic cell voltage level of 1.2 to 1.5V to the other standard voltage level of 5V which is necessary for integral microcircuits control. In our case the capacitor C2 is charged up to a voltage of 385 – 400V.

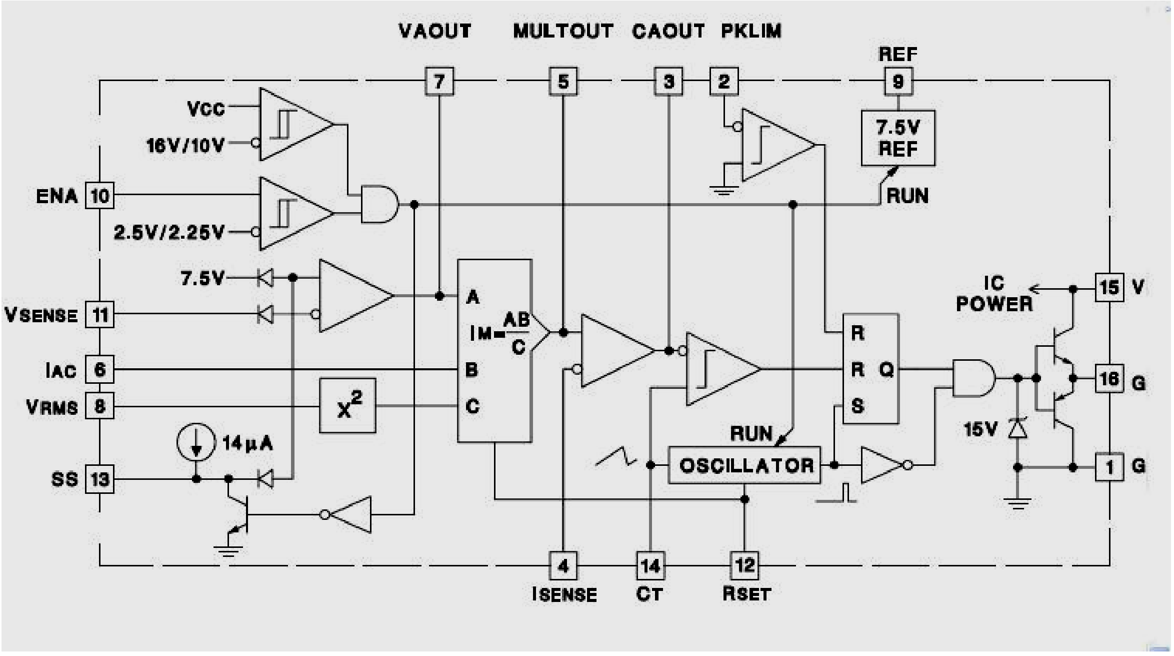

Fig. 5. A microcircuit (UC 1854 type) for buster converter controls

Owing to that capacitor C1 has a very small capacity (it is, per se, only a high-frequency filter) and the control circuit of the switching element with PWM constantly traces a phase of the input alternating voltage and provides a matching binding of the control pulses (that is, pulses of a current carried though the switching element) to a phase of an applied voltage. It is possible to eliminate completely the phase shift between the current and the voltage consumed by capacitor C2, Fig. 3b. Besides the same control circuit provides rigid stabilization of a level of voltage charge on the capacitor C2. Despite the small dimensions of the PFC control microchip, it has a complex internal structure, Fig. 5, and the entire PFC unit is considerably complex and occupies an appreciable area on the SMPS printed-circuit-board, because of the number of addition passive elements, Fig. 6.

The question arises: Why have such complex devices as SMPS expelled such simple and well proven LPS devices from the market?

The basic SMPS advantages over the LPS that are usually specified in the technical literature are:

1. Significant decrease in size and weight due to the smaller main transformer (the high frequency transformer has considerably smaller dimensions and weight in comparison with the transformer of a commercial frequency of the same power).
2. The very wide range of a working input voltage.
3. Considerably higher coefficient of efficiency (up to 90–95 %, against 40–70 % for LPS).

In addition to the above, we would also add one more important advantage: the possibility of working in a network of both AC and DC voltages.

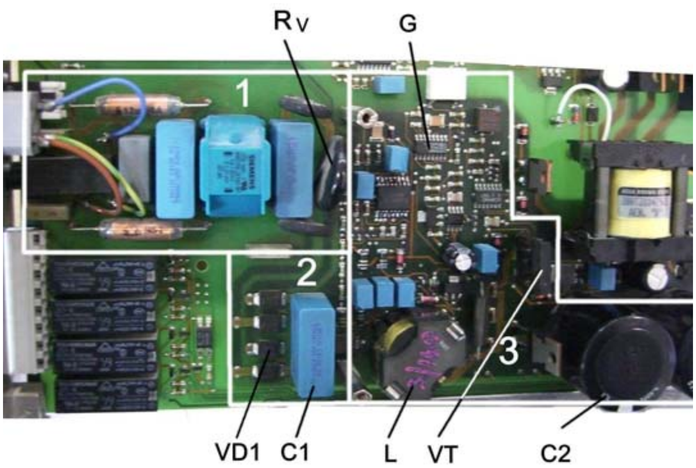

Fig. 6. A fragment of printed-circuit-board with PFC and BC
1 – input filter; 2 – input rectifier bridge with the filtering capacitor; 3 – PFC; R_V – varistor; G – microcircuit for buster converter controls

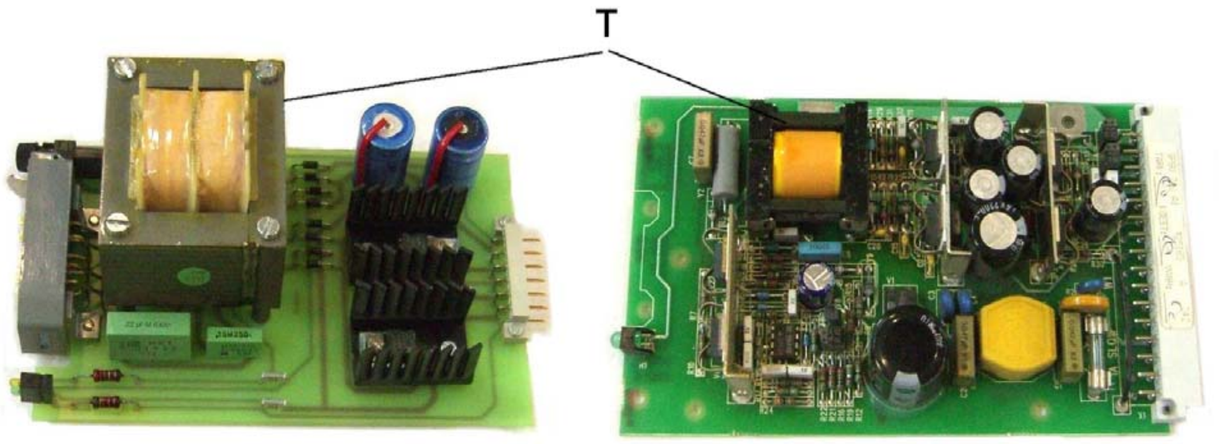

Fig. 7. The linear (at the left) and switch mode (on the right) power supplies with identical characteristics, T - the transformer

At first glance, the differences between two devices, LPS (on the left) and SMPS (on the right), equal in power and properties are readily apparent: the LPS is much simpler, but contains a much larger and heavier transformer (T), Fig. 7.

The flat module SMPS (Fig. 7, on the right) is the universal power supply of microprocessor-based protective relays of such series as SPAC, SPAD, SPAU, etc., which is moved in the relay case. Naturally, to use the relay design of LPS with the large transformer is inconvenient. But, what prevents using three separate small transformers instead of one large transformer with three secondary windings? There certainly is enough space on the printed-circuit-board of LPS. In this case the overall dimensions of LPS will differ not much more than SMPS. Even in the case of a powerful source with one level of an output voltage it is possible to use some the flat transformers connected between themselves in parallel. So, the presence of the small transformer is not an absolute advantage of SMPS.

In connection with the SMPS operational ability over a very wide range of input voltages due to use of PWM in a control system of the switching element, this advantage is touted to us as the essential reason for selecting SMPS over LPS. Well, really, in practice is it important that SMPS can work at the input voltages changing within the limits of from 48 up to 312V? In fact this range comprises at once some rows of rated voltages, such as, 48, 60, 110, 127, 220V. It is abundantly clear that in concrete equipment the SMPS will work at any one rated voltage (changing within the limits of no more than ±20 %), instead of on all of them simultaneously. And if it is necessary to use the equipment with both 110V and 220V voltages, for example, there are well-known solutions in the form of the small switch and tap winding of the transformer to handle this.

The coefficient of efficiency is an important parameter in the case of a powerful power supply, but not in the case of a power supply as small as 25–100 Watts which we are considering. A high coefficient of efficiency and absence of a heat dissipation (that is characteristic of SMPS) can be of some importance in miniature portable power supplies of completely closed systems, for example, as the power supply of laptops. In many other cases, for example, in controllers and electronic relays for industrial purposes, the coefficient of efficiency of power supply is not that important.

The possibility of functioning when fed from a DC network is the only major and absolute advantage of SMPS. The LPS cannot operate in a DC mains power.

Here, in brief, we have given an analysis of the advantages of SMPS in contrast to LPS. We shall now turn our attention to the disadvantages of SMPS.

One of the disadvantages of SMPS is a high level of impulse noise on the power supply output, Fig. 8.

Unlike LPS with its weak 50 Hz pulsation (Fig. 8a), the pulsations of an output voltage in the SMPS (Fig. 8b), as a rule, have much greater amplitude and cover a wide frequency range from several kilohertz up to several megahertz which creates problems with high-frequency radiations that influences circuits within electronic equipment in which SMPS is mounted.

These radiations also affect the wires that in turn affect electronic equipment that is external to the SMPS. Besides in SMPS it is necessary to take steps to prevent the penetration of high-frequency radiations in the feeding power network (from which they are passed and can disturb the operation of other electronic devices) by using of special filters, Fig. 9.

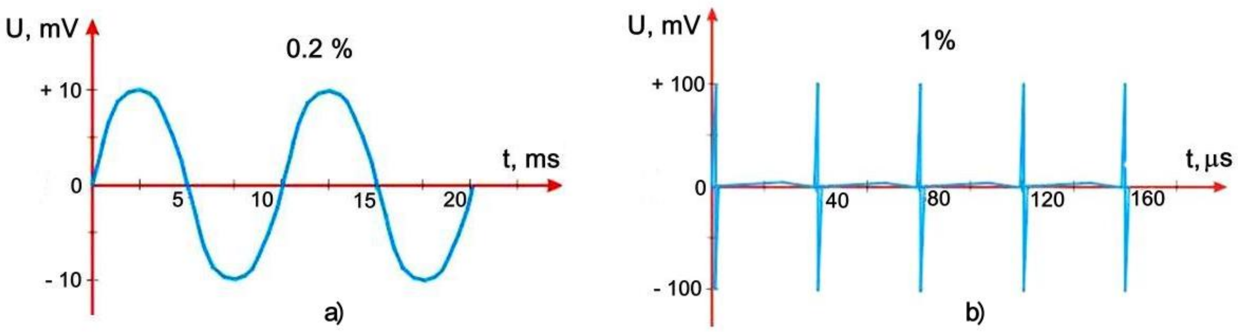

Fig. 8. Typical levels of output voltage pulsations for LPS (0.2%) and SMPS (1%) with an output voltage 12V

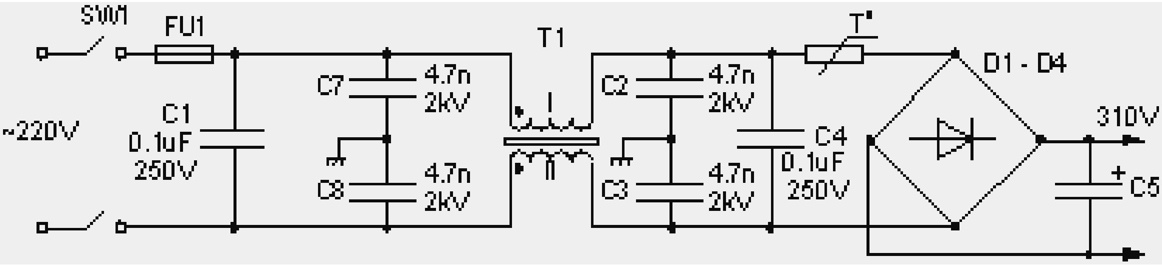

Fig. 9. The circuit diagram of the typical input filter of SMPS

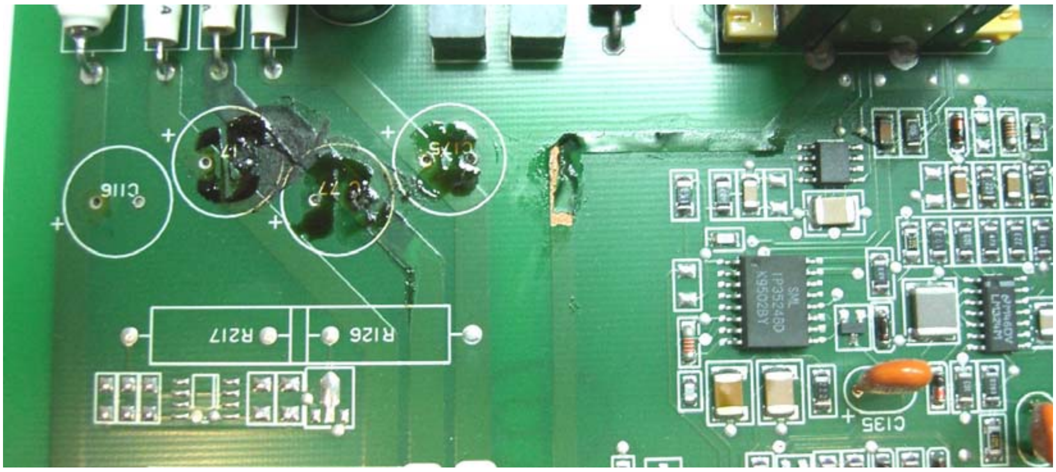

Fig. 10. Destruction of copper streaks on the printed-circuit-board which is taking place under capacitors because electrolyte leakage

The presence of a high-frequency component in the output voltage and in the internal SMPS circuits has led to increased requirements for the numerous electrolytic capacitors that are available in the internal SMPS circuits. Unfortunately, these requirements are seldom considered by engineers in the development process of the SMPS. As a rule, the types of these capacitors are selected only on the basis of their capacitance, operating voltage and dimensions, without taking into account their high-frequency characteristics. However, not all types of capacitors have long life under the effect of a high-frequency voltage, rather only special types having low impedance at high frequencies. As a result such non-suitable electrolytic capacitors often heat up noticeably because of high dielectric losses at high-frequency. The rise in temperature of an electrolyte intensifies chemical reactions inside the capacitor that lead to a speed-up in the dissolution of the capacitor shell and even to an outflow of the electrolyte directly onto the printed-circuit-board, that, in very dense installations, leads to shorting outlets of other elements or breakdown of circuits owing to the dissolution of copper paths of the printed-circuit-board (even despite of presence of a strong covering of paths by a special mask), Fig. 10.

Other well known kinds of SMPS faults that are caused at high temperatures of an electrolyte is the slow desiccation (over several years) of an electrolyte and significant (on 30 - 70 %) decrease of the capacitance that leads to a sharp decline in the characteristics of the power supply, and sometimes full loss of its working capability [1].

For maintenance of effective work of the PFC, the power switching element (it is usually a MOSFET transistor) should possess lower impedance in the conductive state. The value of this impedance largely depends on the maximum operating voltage of the transistor. For transistors with a maximum operating voltage of 500–600V this impedance achieves 0.05–0.3 Ohms, whereas, for transistors operating at higher voltages (1000–1500V) this impedance is one to two exponents higher (for example, 12 Ohm for the transistor 2SK1794 for voltage 900V; 17 Ohm for transistor IXTP05N100 for voltage 1000V; 7 Ohm for transistor STP4N150 for voltage 1500V). It is eexplained choosing the low-voltage (maximum operating voltage 500 to 600V) transistors for PFC. For example, in an actual SMPS design of such crucial devices as microprocessor protective relays and microprocessor-based emergency modes recorders the following transistors types are widely used: IRF440, APT5025, etc. with the maximum operating voltage of 500V. This is definitely not enough for functioning in an industrial electric network with a rated voltage of 220V because of the presence of significant switching and atmospheric voltage spikes. As is known, for protection against such spikes electronic equipment is supplied, usually with the varistors. However, because of insufficient nonlinearity of the characteristic near to an operating point, the varistors are selected so that between their normally applied operating voltage and a clamping voltage there will be essentially enough difference. For example, for varistors of any type intended for operating at a rated voltage of 220VAC the clamping voltage is 650 to 700V. In the power supplies of microprocessor devices mentioned above varistors of type 20K431 are used with the clamping voltage of 710V. This means that at spikes with amplitudes below 700V the varistor will not provide protection for electronic components of the power supply, especially power transistors (500V) that have been connected directly to a main network.

Both the transformer and the coil in PFC have high impedance at high-frequencies that limits a current carried through them and through switching elements. However, a malfunction in the integral microcircuits providing control of the power switching element in PFC or basic power switching element of the SMPS (for example, as a result of an impulse spike) leads to a transition from high-frequency AC operating mode to DC mode (that is, with very low impedance) and a sharp current overloading of the power solid-state elements and to their instant failures. Considering the high density of the SMPS printed circuit board, this often leads to a fault of the near-by elements and burnout of whole sections of printed circuit strips. Generally, as to reliability, it should be absolutely clear that reliability of such complex device as SMPS, containing, as it does, an assemblage of complex microchips and power solid-state elements working at high voltage in a pulsing mode with high rate of current and voltage rise, will be always be appreciable below the reliability of such simple device as LPS containing only some the electronic components which work in a linear mode.

The density of elements on the printed-circuit board and specific power of SMPS constantly increases, for example, an EMA212 type power supply, Fig. 2 (on the right), with dimensions as small as 12.7x7.62x3 cm has an output power 200 Watts. These are found in use in miniature electronic components having surface mount technology (SMT), with a very dense installation of high power elements, and constantly increase of switching frequency. In the past this frequency did not exceed 50 to 100 kHz. Today many powerful SMPS with output currents of up to 20A operate at frequencies of 300 to 600 kHz; and less powerful, for example, those controlled by an ADP1621 type integral circuit, operate at frequencies of 1 MHz and more. This promotes the further decrease of SMPS mass and dimensions. This tendency in SMPS evolution has been advertised as the great advantage of SMPS. The downside of this is the practically full loss of maintainability of the SMPS. It is a source of serious problems for the user of SMPS. The problem is not only additional expenditures for purchasing a new SMPS devices, but also the fact that not all SMPS input/output connections are of unified sizes and forms. They can be made in the form of special rigid connectors, or as terminals with screws, or as a flexible conductor with a connector at end, Fig. 11, and also can be made as two parts of rigid connectors placed on the printed-circuit-board (first part) which are moved in on directing in case of the equipment up to contact with mother-board (second part).

Such lack of uniformity in SMPS design leads to the impossibility of replacing a damaged SMPS of some type which, as a rule, resides inside the equipment, with an SMPS of another type if the old SMPS is not manufactured any more. The SMPS are being updated constantly, therefore those that malfunction after the passage of some years of maintenance inside complex equipment, before a user there is a challenge: when and how to replace this damaged SMPS? The author repeatedly had to solve this puzzle by purchasing more compact new type of the SMPS and its housing in the old case, or placing a new open type SMPS on an old printed circuit board of old SMPS. All these tricks do not add points in favor of the SMPS.

Fig. 11. Some types of the input/output connections used in SMPS

In the sophisticated systems of industrial automatics and power engineering many different electronic devices are applied: measuring converters (transducers), controllers, etc., installed in the control cabinets. As a rule, each of these devices has its own built-in power supply. Because of the aspiration to reduce the sizes of devices and to reduce the price of them, the built-in power supplies are very simplified (often even with damping resistors instead of insulating transformers). And the element baseline of such sources is effected using rather low-cost elements which do not have adequate reserves of power and voltage. As a result, such devices often fail owing to running out of power supplies. However, are such power sources necessary in these devices? The question can be put even more broadly: whether the built-in power supplies in the electronic devices for industrial purposes intended for installation in control cabinets together with tens of other analogous devices are necessary in general? Why not release in completely automatic systems (in the control cabinet) such devices as control units, electronic relays, electronic transducers, etc. without power supplies, and only with a connector intended for connection of an external power supply? This external power supply installed in the control cabinet should be, in our opinion, linear, to have a good power reserve, should be supplied by necessary elements for overvoltage and short circuit protection. Moreover, in the control cabinets in reference to automatic systems with increased reliability, such LPS should be two and may connect among themselves through a diode (a so-called “hot reserve”). It may seem strange but in the epoch of SMPS there are many companies (VXI, Lascar, Calex Electronics, Power One, HiTek Power, R3 Power and amongst many others) that are continuing to manufacture LPS. This testifies to their popularity in certain areas of techniques and to their accessibility to practical applications. In our opinion, the approach specified above would allow considerably increasing the reliability of the automatic systems such as remote control, relay protection, etc. (with a mains supply of an alternating current) without increasing its cost (owing to the smaller cost of electronic devices without the built-in power supplies).

An analogous approach can be used and in the case of feeding the electronic equipment (for example, the same microprocessor protective relays) installed in the control cabinets from a network of a direct current, with that only a difference that two power supplies should be SMPS instead of LPS. Thus these SMPS should be subjected to serious redesign. First, the power factor correctors as absolutely senseless units for mains supply from direct current should be dropped, this in itself will increase the reliability of SMPS. Secondly, those SMPS intended for installation in control cabinet should be large enough (in such SMPS it is senseless to pursue for compactness) and convenient for repairing, they should not contain miniature SMT elements. Thirdly, the numerous electrolytic capacitors that are available in SMPS should be concentrated on a separate printed circuit board intended for its simple replacement after each 5 years of maintenance (that is, before the capacitors start to fail). The main filter should be used as a complete device (hundreds models of such filters are present in the market), instead of assembles from separate elements so it is possible to replace simply and quickly in case of need.

The solutions we offer, in our opinion, will allow lowering dependence of the stationary electronic industrial equipment on secondary power supplies and considerably increase its reliability.

In summary, some words about the newest trends which have appeared in the design of secondary sources of power supplies: the attempt to use microprocessors in both in LPS [2], and also in SMPS [3]. It may be that our view seems excessively conservative to the reader, but, in our opinion, microprocessors are necessary in power supplies as well as in toilet seats where microprocessors are employed to measure temperature exactly of a matching part of a body and heating the seat up to the temperature for comfort. It has become abundantly clear, as we have pointed out, that the presence of functionally unnecessary complex units in the equipment is the univocal way leading to decreasing its reliability.

References

1. Gurevich V. Reliability of Microprocessor-Based Relay Protection Devices – Myths and Reality / V. Gurevich // Engineer IT. Part I: 2008 – N 5. – P. 55–59 ; part II: 2008. – N 7. – P. 56–60.
2. Sadikov U. Power supply as a network adapter with adjusted voltage 1.5 to 15V and output current 1A / U. Sadikov // Electronics-Info. 2008. – N 12. – P. 42–43.
3. EFE-300/EFE-400. 300/400 Watts, Digital Power Solution. – Datasheet TDK-Lambda, 2009.

ВТОРИЧНЫЕ ИСТОЧНИКИ ЭЛЕКТРОПИТАНИЯ: АНАТОМИЯ И ПРИМЕНЕНИЯ

В.И. Гуревич

В статье описаны конструкция и характеристики линейных (ЛИП) и импульсных (ИИП) источников питания и выполнено сравнение между ними. Показано, что часто ИИП имеют неоправданно сложную структуру, очень высокую плотность монтажа и они менее надежны, чем ЛИП. Предложено использовать устройства автоматики, защиты и управления, смонтированные в шкафах, без встроенных источников питания. Для обеспечения электропитания этих устройств предлагается использовать два общих на шкаф линейных источника питания: основной и резервный.

Ключевые слова: линейный источник питания, импульсный источник питания, корректор коэффициента мощности, широтно-импульсная модуляция, бустерный конвертор.