



RELIABILITY OF UNINTERRUPTED POWER SUPPLY DEVICE DC UPS 400

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Content: *The paper describes uninterrupted power supply with DC output voltage – DC UPS 400 with emphasis on reliability. Its purpose is to provide uninterrupted work for IT (information technology) class devices. Reliability calculation procedure was done in several steps. The first step is known theoretical calculation method. However, due to existence of some parasitic capacitance and inductance in the converter, voltage and current of switching elements are different from the theoretical. Therefore, the wave forms are recorded only on a working device. The paper presents wave forms recorded on components critical in a way of reliability criteria by theoretical calculation. Starting from recorded wave forms analysis of reliability has been redone. Experience obtained during many years of development and testing of power electronics devices is used in analysis. All measurements, recordings and testings were done in laboratory conditions. Based on the results, values of critical elements are corrected in order to increase device reliability.*

Key words: *uninterrupted power supply/DC output voltage/reliability*

1. INTRODUCTION

Purpose of uninterrupted power supply device is to provide power supply for consumers from backup source when interruption in supplying from primary source occur. The switching time, from primary to backup source should be short enough not to cause interruption in the work of consumers powered over uninterrupted power supply device. Reliability of all consumers connected to the power source over uninterrupted power supply device depends on its reliability.

Qualitative data on the reliability of a device can be determined in three ways: by theoretical calculation, experimentally (testing in extreme conditions) and during exploitation (analyzing device time to failure and correcting the initial solution).

In the paper are analyzed reliability of uninterrupted power supply device (DC UPS) by combination of all three ways. Emphasis is placed on components expected to be critical. Wave forms are recorded on these components and the reliability is calculated.

In Iritel, DC UPS is standard production device since 2004, but it is still under testing and upgrading in order

to obtain greater reliability in operation, thus obtaining better and more economical solution.

2. DC UPS AS A SOLUTION FOR UNINTERRUPTED POWER SUPPLY

At the XI Telekommunikation forum, TELFOR, 2003, a work that describes principle of the device for uninterrupted power supply with DC output voltage (DC UPS) was published for the first time. It is a solution where a backup power source is parallel connected with the main source of energy. The special part of this solution is that DC output voltage generates on the output. Therefore, we will proceed from the assumption that on the consumer input is switch mode power supply. The disadvantage of this solution is limited application area because DC UPS can not be connected to devices that have a linear power supply or asynchronous motors on input. However, all devices from information technology group have the power switch, and DC UPS is the best solution for ensuring uninterrupted operation.

As it has a DC output voltage, this approach has all the advantages of uninterrupted power supply with DC output voltage.

The main advantages are real continuity, high efficiency, simple and reliable work and low cost.

3. RELIABILITY CALCULATION

Reliability can be expressed in several ways, or, different reliability indicators. Primary reliability indicators of components and systems are:

- Failure distribution function
- Reliability function
- Failure density function
- Failure intensity
- Middle time to failure and time between failures

Failure distribution function $F(t)$ is represented with expression

$$P(T \leq t) = F(t), \quad t \geq 0 \quad (1)$$

where T is random variable size which indicates time of failure, and $P(T \leq t)$ failure probability in the function of the time.

Function $F(t)$ is failure distribution function and shows probability that system will cancel by the time t .

If examined system is renewed by maintenance or repairing, expected nonfailure time is known as **middle time between failures (MTBF)**. In this, we start from a presumption that behavior of repaired system, in terms of failure intensity, is equal as of a new system. With so-called repairable systems we talk about middle time to failure (MTTF).

Middle time between failures is calculated:

$$MTBF = \frac{1}{n} \sum_{i=0}^n t_i, \quad (2)$$

where n is number of observed devices, and t is time to failure.

4. RELIABILITY MODEL FOR UNINTERRUPTED POWER SUPPLY DEVICE

To calculate the reliability parameters of a device, it is necessary to set up a model of reliability. Reliability model consists of a block diagram combination, the failure distribution definition and repair for system parts, status definition for system parts and determined strategies regarding the maintenance of spare parts. Block-diagram represents a graph which, using blocks and lines, describes system parts failure effect and system functioning ability.

Formula for calculating reliability represents mathematical relationship between reliability of system parts marked with blocks at reliability block-diagram. Considering all aspects that affect system work and taking into account tasks which system must do, we could define satisfactory state of the system and unsatisfactory state of the system, as well as the way these states could be achieved.

The process that is necessary to follow in the calculation of a device reliability predictions consists of 8 parts:

1. System definition
2. Failure definition
3. Definition of operating and maintenance conditions
4. Block-diagram reliability construction
5. Setting formulas for reliability calculation
6. Determining intensity of failure for system parts
7. Failure intensity modification of system parts
8. Calculate the system reliability.

The below is given a theoretical explanation of reliability prediction calculation for DC UPS 400 and the reliability calculation of critical components in the system.

1. DC UPS is a device for uninterrupted power supply with DC output voltage. The main power source is network voltage (230 or 110 Vac), and spare sources are often batteries. When there is an interruption in energy supply from main source it will automatically (interruptible) switched to the reserve source. The devices can be divided into two main parts: power electronics subassemblies and control electronics subassemblies. A control electronics subassemblies is stable and more or less noncritical in terms of failure. A power electronics subassemblies could be divided into several parts (figure 1) from which some

are more prone to failures, while others work in a less critical conditions. The control electronics subassemblies could be divided into parts: power supply, initial power supply, undervoltage protection, for current measuring and current protection. Critical elements are in the power electronics subassemblies. These are power switches - mosfets and diodes. Comutation period is critical, opening and closing of power switches. Existence of some parasitic capacitance and inductance in power switches, can produce overvoltages on inductive and capacitive components and power switches failure. It must not be neglected the phenomenon that in comutation period significant power are disipated at power switches as a result of electric current flow through the switch. Two rows with three diodes are placed on transformer secondary side. To reduce overvoltage on diodes serial connection of resistors and capacitors is used („snubber“ network). On the secondary side of diodes maximum voltage is limited to around 1500V. Snubber network is dissipative network and compromise between degree of efficiency and maximum surge at power switches must be find. Reduction of overvoltages with snubber network increase resistor power in snubber network, and also reduces efficiency.

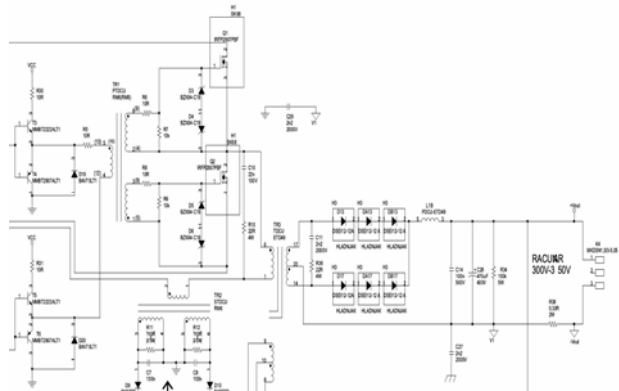


Fig. 1. Power electronic part of DC UPS

2. System failures can occur due to incorrect work of control or power electronics. Power switch failure on primary or secondary side causes work interruption and disfunctionality of DC UPS. Failure of control electronics leads to failure of inerruptableness of DC UPS output. However, if the main source is active, output of DC UPS will remain in operation. Failure of input power electronics subassemblies will cause that consumer is supplied constantly from the backup power source. Powered device will work as long as there is energy in the backup power source. Failure of the output manifests same as power switch failure, like complete operation stop. Undervoltage protection failure will not affect the uninterrupted power supply device operation. Overcurrent protection failure will not affect operating of DC UPS, but there will not be protection from overload. Therefore, the critical failures are failures in the middle part of DC UPS, power switches mainly.

- Working conditions of one DC UPS are the same like other PC or any other computer equipment. It means that in most of the cases they work in normal working conditions which increases system reliability.
- On a block-diagram reliability blocks are connected serially which make device stop working if they fail. In the case of parallel connection in the block-diagram, one block failure does not imply system failure. Therefore, only cancellation of all parallelly connected blocks get to device failure (Figure 2).

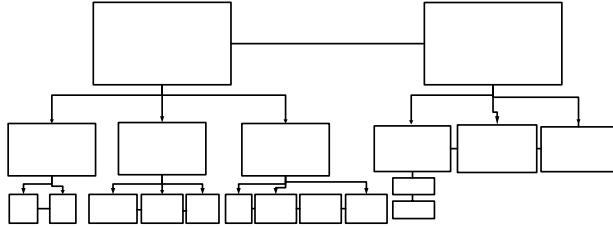


Fig. 2. Block reliability diagram

- After testing, research and long time experience, we came to the conclusion that most critical components are fets and diodes in subassemblies of power electronics and elements in networks which should reduce overvoltages at power switches and diodes. We could get real picture about reliability of whole device by calculating reliability of most critical points (components) (Figure 3).

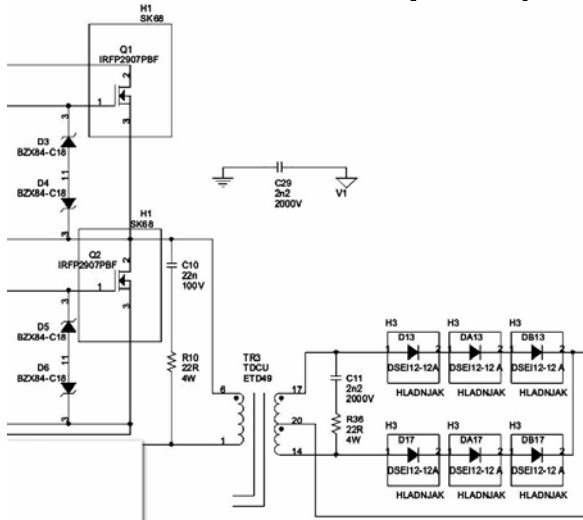


Fig. 3. Critical points of system reliability

When calculating reliability of environmental factors, capacitance and resistance factors and quality factors $\pi_E, \pi_{CV}, \pi_R, \pi_Q$ values were taken from the literature [1].

Constants $N_S, B, N_T, H, J, \Delta T$ were also used from the literature [1].

- FET's reliability is calculated by formula

$$\lambda_p = \lambda_b (\pi_E * \pi_A * \pi_Q * \pi_C) \text{ failure} / 10^6 h \quad (3)$$

$$\lambda_b = A * e^{\left(\frac{N_T}{273+T+(\Delta T)S}\right)} * e^{\left(\frac{T+273+(\Delta T)S}{T_M}\right)^P} \quad (4)$$

$$S = \frac{V_{radno}}{V_{FET}}, \text{ ratio between working voltage and used FET's voltage.}$$

Gained value for FET's reliability is:

$$\lambda_p = 0.00682 * 10^{-6} \text{ failure} / h$$

- Reliability for used diodes is calculated by formula

$$\lambda_p = \lambda_b (\pi_E * \pi_R * \pi_Q * \pi_A * \pi_S * \pi_C) \text{ failure} / 10^6 h \quad (5)$$

$$\lambda_b = A * e^{\left(\frac{N_T}{273+T+(\Delta T)S}\right)} * e^{\left(\frac{T+273+(\Delta T)S}{T_M}\right)^P} \quad (6)$$

$$S = \frac{V_{radno}}{V_{diode}}, \text{ ratio between working voltage and voltager of used diode.}$$

voltager of used diode.

$$\lambda_p = 0.00322 * 10^{-6} \text{ failure} / h$$

For FET's and diodes operating voltages were taken also, values which were expected for a certain configuration. 30V for FETs, and 1000V for diodes.

Voltage on diodes, in real terms is about 600 - 700 V, but because of assumptions about the peaks the value of 1000 V was taken. C10 and C11 are elements that need to protect diodes from overvoltage.

- Capacitor reliability is calculated by formula:

$$\lambda_p = \lambda_b (\pi_E * \pi_{CV} * \pi_Q) \text{ failure} / 10^6 h \quad (7)$$

$$\lambda_b = A * \left[\left(\frac{S_{power}}{N_S} \right)^H + 1 \right] * e^{\left(\frac{T+273}{N_T} \right)^G}$$

$$S = \frac{V_{radno}}{V_{kond}} \text{ ratio between working voltage and capacitor voltage.}$$

For working voltage it is taken expected value 80 V for capacitor C10. That is, 1000V for capacitor C11. Operating temperature is 25°C.

Reliability value obtained is

$$\lambda_p = 0.004641 * 10^{-6} \text{ failure} / h \text{ for the capacitor C11 value } 2n2 / 2000 \text{ V.}$$

Reliability value obtained is

$$\lambda_p = 0.02026 * 10^{-6} \text{ failure} / h \text{ for the capacitor C10 value } 22n/100 \text{ V.}$$

Reliability value obtained is

- Resistor reliability is calculated by formula:

$$\lambda_p = \lambda_b (\pi_E * \pi_R * \pi_Q) \quad (9)$$

$$\lambda_b = A * e^{B \left(\frac{T+273}{N_T} \right)^G} * e^{\left[\left(\frac{S}{N} \right) \left(\frac{T+273}{273} \right)^J \right]^H} \quad (10)$$

$S = \frac{P_{radno}}{P_{otp}}$, represents ratio between working

voltage and prescribed power for used resistor.

Working temperature is $25^\circ C$.

Used resistors are 4W of power and value is 22Ω .

Gained reliability value for resistor R10 is

$$\lambda_p = 181.615 * 10^{-6} \text{ failure/h}$$

And for resistor R36

$$\lambda_p = 81.899 * 10^{-6} \text{ failure/h}$$

To calculate working power, expected power values for certain configuration were used. These values correspond with RMS voltage values that is shown on Figures 4. and 7, chapter 5.

6. Production of DC UPS started in 2004 after research and testings. From 2006 to 2009, 120 devices were delivered, in average, 30 pieces per year. Out of all delivered devices, about 5% failed. After failure diagnostic it was noticed that around 50% of failures were caused by inadequate device usage. To the remaining 50% of all delivered devices malfunction happened because of mosfets, diodes or capacitor C11 failures. Reliability calculations for these devices were done at point 5.
7. As it was pointed out earlier, DC UPS's work in normal working conditions which leads to failure reduction. Of all surveyed devices, the highest percentage of failures happened on devices that work under hard working conditions (high or low temperature, bad main power supply, a common atmospheric discharge).
8. Because this paper deals with the reliability, primarily of critical components, the reliability of the whole system will not be considered.

5. POWER MEASUREMENT ON THE RESISTORS AND CAPACITOR

Figures from 4 to 7 show voltage wavew shapes at „critical“ resistors and capacitors which reliability was calculated. On Figure 4 voltage at the resistor R10 is showed. Medium voltage is 600 mV, peak value is 26 V, and RMS is 2.95 V. Next, Figure 5 shows voltage on the capacitor C10 and gained values are: peak value 60 V, RMS 16.8 V. We can see that voltage value is lower than value used for reliability calculation. It means that reliability of this capacitor is higher then calculated theoretical values, which increases whole system reliability. Figure 6 shows the wave shapes at the entrance of the transformer TR3 (resistor R10 and capacitor C10).

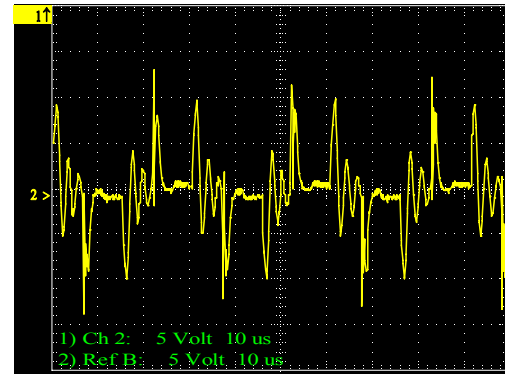


Fig. 4: voltage at the resistor R10

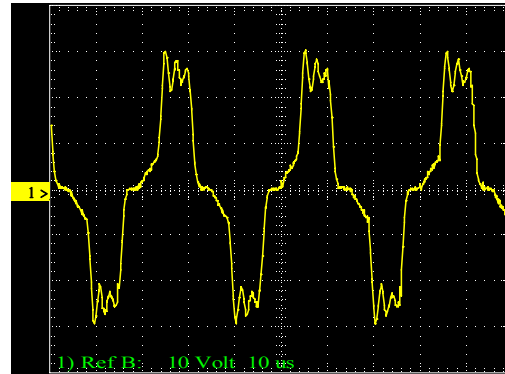


Fig. 5: power on the capacitor C10

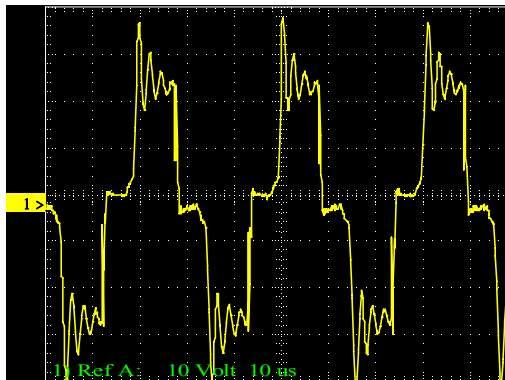


Fig. 6: measurements on resistor R10 and capacitor C10

Figure 7 shows the voltage at the resistor R36. Medium voltage is 50 mV, measured peak value 35.2 V, and RMS 5.11 V. Next, Figure 8 shows voltage on the capacitor C11 and values are: peak value 3.08 kV, RMS 655 V. Figure 9 represents measurement on the output of transformer TR3 (resistor R36 and capacitor C11). In the reliability calculation it was taken expected voltage value of the capacitor (1000 V). Measurement showed that the value exceeds the expected due to the occurrence of peaks from 500 V. Therefore the reliability value changes, or, capacitors reliability reduces as well as system reliability.

Selected capacitor, rated voltage 2000V, can not hold the value of 3000 V. In the capacitor short circuit occurs which causes diodes order D13 or D17 failure. One of the changes at the DC UPS device after completion of measurements is replacement of capacitor values. The capacitor must to withstand much higher voltage whereby value of 3000 V would not be a problem in the work.

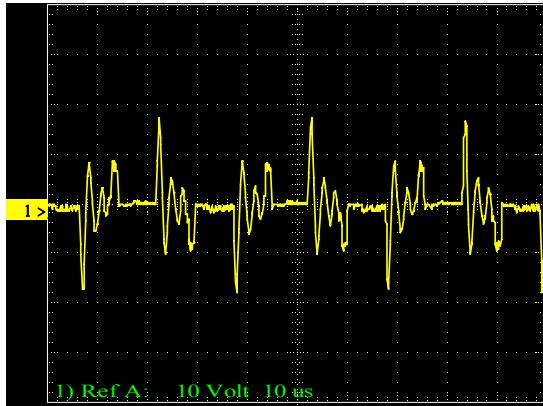


Fig. 7: voltage at the resistor R36

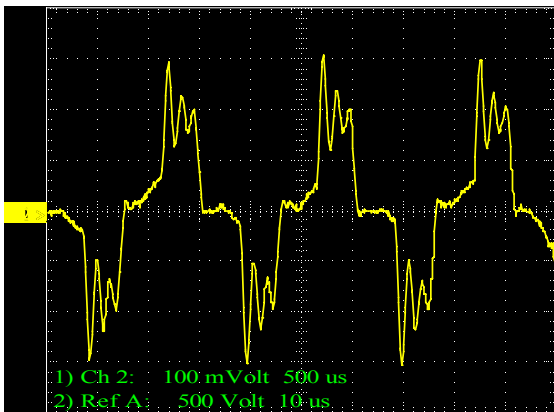


Fig. 8: voltage at the capacitor C11

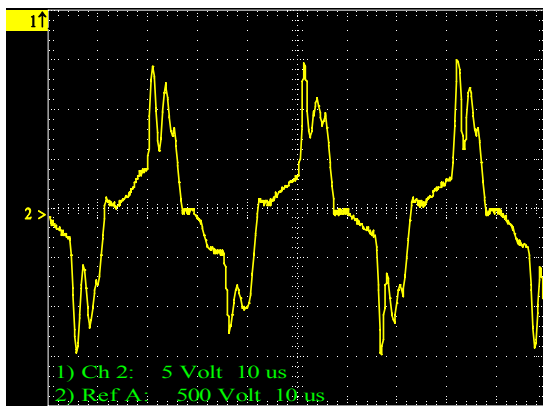


Fig. 9: measurement at the resistor R36 and the capacitor C11

Voltage measuring on the resistors (peak value) gave values which are much higher than the measured RMS value, and therefore power which exceeds power predicted for a given resistor. To provide FET's and diodes protection, in given "snubber" network configuration, resistors need to endure measured voltage peaks. Realistically speaking, during a switch period

maximum peak voltage could occur, but that value is not continuous and therefore selected resistor can withstand (dissipate) maximum power. In the case that selected resistor has less power (it would also be enough for voltage medium value at the resistor) after a while it will get to resistors overheating, change of his resistance and failure, of course. In that case, low-power resistor could not dissipate power which happens during maximum voltage peaks. Therefore, it is necessary to find a compromise solution for resistors in order that protect FET's and diodes need to be high-quality.

6. CONCLUSION

Theoretical reliability calculation, makes components choosing a much easier to the designer. However, only after practical using and longer exploitation can be shore if a component corresponds to the given configuration. In desining of the DC UPS it was started from a position that the device's "critical points" are known. After calculating the reliability of certain components, a selection was made. The converter is optimized by principle of maximum efficiency. Overvoltages and oscilations that not affect the consumer's work are allowed in order to maximally reduce loses at snubber networks. However, only after long period of testing, measuring and recording of real situation, mistakes were perceived and some changes were done. From the production beginning, device has undergone many changes which increased reliability. Theoretical calculations were corrected after finishing of the development and recording voltage form on a realized device. So, the maximum voltage expected for capacitor C11 is 1000 V, 3,2 kV was obtained, therefore it has to be replaced. After delivery to the user, the device operation is monitored and any change or cancellation mode, carefully examined and tested. On this basis we come to final conclusions about new components selection and reliable configuration.

7. LITERATURE

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