Fault tolerant power supply systems

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***Abstract* — In the case of difficulty accessible data collection system, is important the long-term correct operation, because it is not economical to often service it. For example, a weather monitoring, data collecting and transmission system's elements, which are far from inhabited areas. In this kind of electronic systems need to use more failure-tolerance than our day-to-day life used electronics. In this article, the focus is on the solution of an embedded system, which controls the redundant electronic power supply unit.**

I. Introduction

A. Theory

Reliability is a predicted number, which is based on collected data of the failures and calculated probability. A reliable system is does not let the system work, in case of some defined type of failure. But a fault-tolerant system, will work even if the system suffers some type of predefined failure. Failures can be single or multiple, based on design. Both in critical (like nuclear power plants) and in non-critical systems (like our example), the handling of fault-tolerance is very similar. Fault-tolerance is implemented into the system, as a combination of hardware and software.

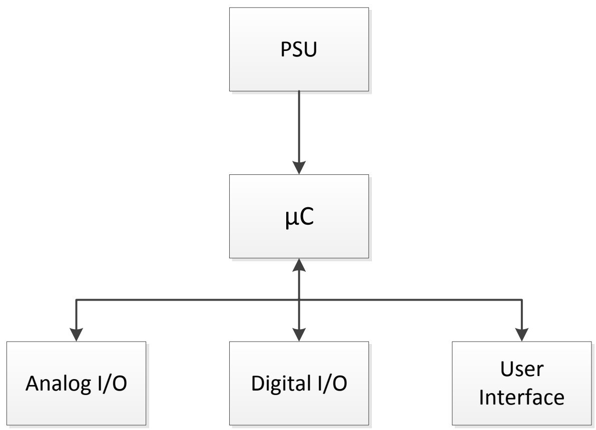


Figure 1. How conventional embedded systems are implemented

In conventional embedded systems, components and peripheries are around the microcontroller, it can be a system on chip (SoC), a printed circuit board (PCB) or separated modules (Fig. 1.). In a fault-tolerant system, the critical components are duplicated, or critical systems components are also can be multiplied. The fault-tolerance system's level is depending of the criticality of the applications. In a basic architecture are designed to handle single faults. Handling multiple faults case increasing reliability, costs and complexity.

In our example consequences can't be that serious if failure happens as an aircraft main controller failure, so we do not need to make redundancy in microcontroller level.

In our realization, we have got two parallel power supply units (PSUs are frequently failing units), and if one of them fails, their pair will take over the role (Fig. 2.). This means, at a time only one is working, and take 100% of the load, the other is waiting or it is currently being under a measurement process. With this redundancy is able to ensure the power supply fault-tolerant nature. This mode is also known as hot-stand-by mode.

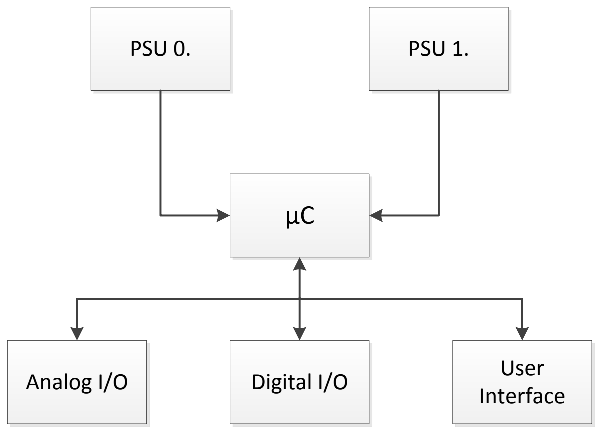


Figure 2. How duplicated PSU based fault-tolerant systems are implemented

Another solution is, when PSUs are sharing the loading current equally. If there is more than two PSU in the system, then they are sharing the load proportionally when one of the PSUs falling out from the operation. The remaining PSUs individual loads are still under 100%. For example, if there is four redundant PSU in the power supply system, and one of them suffers some failure (the monitoring system turns it off), the remaining PSUs are sharing the load equally, so instead of 25% of the loading current, they need to provide 33%. Each PSU are should be capable to provide the full loading current if it is necessary. [1]

B. System design

In redundant PSU fault-tolerant systems there are a few basic points that need to be implemented into the system, such as:

- In hot-stand-by mode or load-sharing mode, the embedded monitoring system should be able to notify the central management system about the actual condition of the PSUs or if there is a failure.
- The monitoring system need to test the PSUs in hot-stand-by mode. It should swap the PSUs periodically or use an external load.
- The power supply system should have the possibility – even in load-sharing mode – to hot-plug-in the individual PSUs, and insure the conditions of smooth running for the main system.

In a fault-tolerant system, with redundant PSUs, there are two type of the controlling system. In the first case there is only one microcontroller, then the main system controlling the main functions (like measuring, logging, communication, etc.) and also handling the power supply system (monitoring, testing and evaluating the PSUs, controlling the switching unit, etc.).

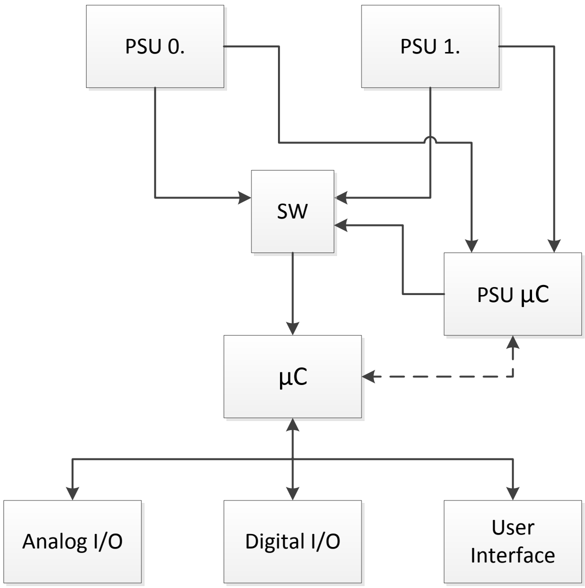


Figure 3. How duplicated PSU based fault-tolerant systems are implemented

Our system is containing duplicated power supply units, and they need to be prepared some basic functions, like measuring effectivity, temperature, etc. In our realization, the main system is do not need to explore, if one of the PSU is suffers some kind of failure, the monitoring system will find it if there is some dysfunction, and notify the main system. The monitoring system is managing the PSUs trough the switching unit. The main system will notify the central management system from the fault trough the applied communication protocol. Using them alternately, to test them time to time. The system has the feature of PSU hot-plug-in to ensures smooth running, and it also ensure uninterrupted running when the monitoring system swap the PSUs by the reason of testing or some kind of PSU failure of when the service personnel changing the PSU modules. The block diagram of the system can be seen in Fig.3.

II. Realisation

A. Measuring the PSU condition

[2] The most common source of the problem in a power supply, is from some switching or regulating element, typically a MOSFET. It can be a stand-alone component, or a part of an other, more complex component. With power MOSFETs switching can be very fast, resulting in low switching losses, but there are still some losses. The main drawback is $R_{DS(on)}$ and its strong positive temperature coefficient.

$$T_{ep(on)} \approx 6 \ldots 9 \cdot 10^{-3} \left[\frac{1}{°C} \right], \tag{1}$$

where $T_{ep(on)}$ is the temperature coefficient of the epitaxial layer.

The main components of on resistance $R_{DS(on)}$ include the channel, accumulation layer, drift region, and parasitic (metallization, bond wires, and package). The effect of the loading current is really weak for the $R_{DS(on)}$, as Fig.4. shows.

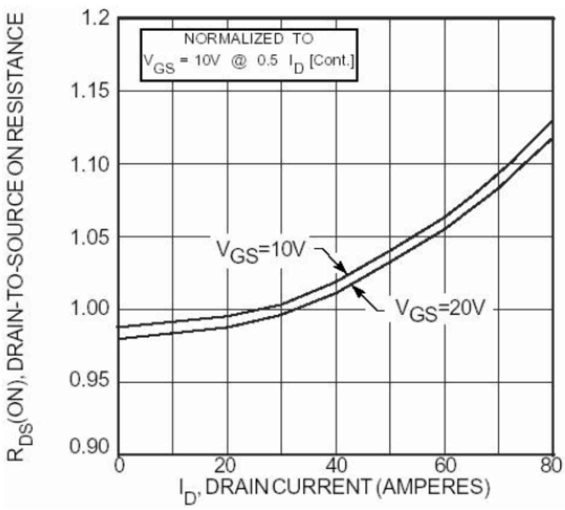


Figure 4. Drain to source on resistance vs. drain current [2]

At the other hand, temperature has a strong impact to the drain-source resistance (Fig.5.). A ΔT temperature difference cause a higher drain-source on resistance:

$$R_{DS(on)} = R_{DS(on)25} \cdot \left(1 + \Delta T \cdot T_{ep(on)}\right), \tag{2}$$

where $R_{DS(on)25}$ is the drain-source on resistance at 25°C.

If the transistor's temperature changes from 25°C to 125°C, the drain-source on resistance approximately doubles. It is able to use for a quick estimation the following correlation:

$$R_{DS(on)125} \approx 2 \cdot R_{DS(on)25}, \tag{3}$$

where $R_{DS(on)125}$ is the drain-source on resistance at 125°C.

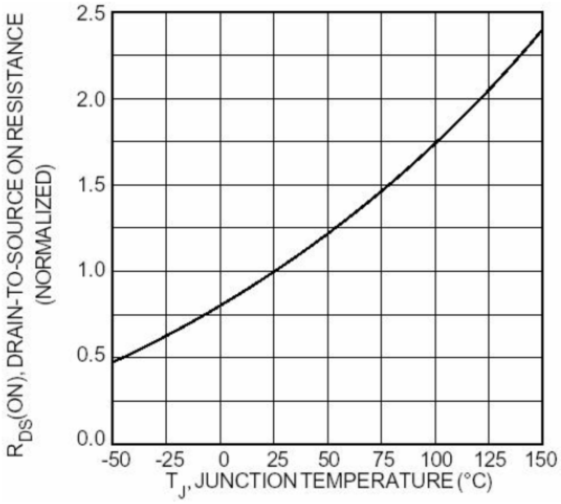


Figure 5. Drain to source on resistance vs. junction temperature [2]

The momentary power loss is depending from the flowing current and the drain-source on resistance (in ohmic range):

$$p(t) = i_D^{\,2} \cdot R_{DS(on)}, \tag{4}$$

where $p(t)$ is momentary power loss and $i_D^{\,2}$ is the momentary drain current.

Because the drain-source on resistance will grows if the layer temperature is higher, the power loss also will grow, the efficiency will be lower.

The positive $R_{DS(on)}$ temperature coefficient is a nice feature when paralleling power MOSFETs because it ensures thermal stability. It does not however ensure even current sharing [3]. What makes MOSFETs easy to use parallelly is their relatively narrow part-to-part parameter distribution. It is advantageous to keep the gate-source voltage at the same level at all of the parallelly connected transistors, then approximately the same current will flow through them. Conversely, it is not recommended for the gates to directly connect each other, because the capacitive type gate inputs and scattered inductance can cause unwanted high-frequency vibrations. In order to avoid vibrations, it is useful to connect serially a small value damping resistors with the gate.

The monitoring system is measuring the input and output power of the PSU, by measuring the voltage and current in the primer and the seconder side of the unit. For these value it calculates the efficiency of the PSU, if this value is under a predefined level, or after multiple measurements says the unit's condition is deteriorating (the efficiency is decreasing more than the allowed slope), the monitoring system is sending an error signal to the main system, and swapping the power supply units.

B. *The switching unit*

The monitoring system controlling the switching unit to choose one of the PSUs, to supplies power to the main system. The switching unit is containing switching elements. In practice, these are MOSFETs, these are fast and simple to use components.

As any other components MOSFETs also can go out of order. In the first case it can go to short-circuit (it can't be turn off), and at the other hand, it can go to connection-cut (it can't be turn on). Both way can cause some malfunction in the operation of the system.

To increase the fault-tolerance level of the switching unit, it need to be increase the number of the switching components. If there are multiple the number of the MOSFETs, the probability of some type of faulty is much lower.

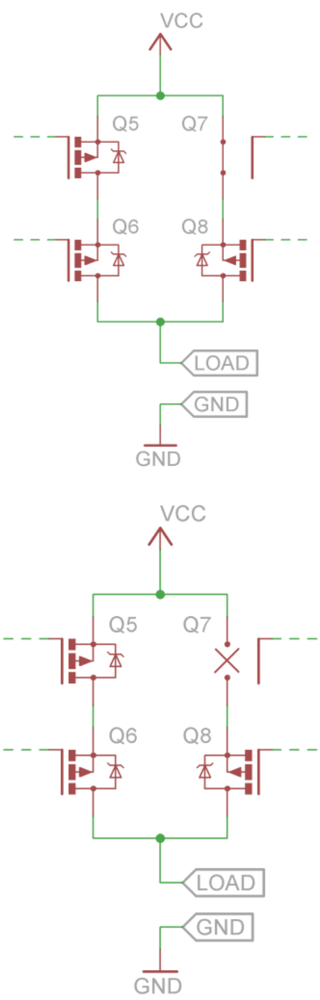


Figure 6. Example for redundant switching components and their fault-tolerance behavior in different type of faults

If there is two serially connected MOSFETs instead of one, and the one of it goes to short-circuit (it does not matter which), then the switching unit is still working properly, because, the other MOSFET can turn on and turn off the line. But, if one of the MOSFETs goes to connection-cut, the line can not be turn on again.

If there is two parallel line, which each are contains two serial MOSFETs, then, if one of the MOSFETs suffers a connection-cut, the other – the parallel – line can take the load, and the switching element still can work properly (see at Fig.6.).

In the switching unit, in one switching element, all of the switching devices (the MOSFETs) are controlled parallel.

When switch-over the PSUs, there is a short period of time, when none of the PSUs are connected to the main system. To avoid blackout, it is need an energy storage device. Practically a capacitor, this allows a smooth switching.

III. A INTRODUCTION OF HARDWARE AND SOFTWARE

A. Measuring the PSUs

To determine the goodness of the PSU, is based on calculating the efficiency. If the efficiency drop down, then it is a sign for a future failure (it can cause higher internal resistance for example). To calculate the efficiency, it is need to measure the input and the output power.

In our example we use a DC-DC power supply, and measuring the voltage and the current as well. The voltage measurement is based on a voltage divider, and after a protecting circuit, the microcontroller is measuring it, with an inner ADC periphery. For the current measurement, a hall sensor provides the measured analogue voltage which is proportional to the flow through current. After the measurement of the primer and seconder side, the efficiency is easily calculable.

The monitoring system is carrying out measurements. If the efficiency is dropping under a predefined level, or after compared to the previous measured values and the slope of the efficiency change is too high, the monitoring system will swap the PSUs, and send an error message to the main system, and also the type of the fault.

B. Faults of the PSUs

There is other type of faults that the PSU can suffer, and can be harmful for the main system. The monitoring system is prepared to recognize the next ones (Fig.7.): over current; over and under voltage; voltage fluctuations, voltage ripple, unstable voltage output and no voltage output.

C. The prototype and the program

The modell of the system and the develoopong area can be seen at Fig.8. The monitoring system is implemented to an AVR microcontroller. The program is written a C based programming language.

To setting the parameters of the monitoring system is allowed, it can be set all the measuring parameters and the periodicity of the measures, also can turn on and off the other tile of failure checking, and the error messages. The flowchart of the monitoring program is visible at Fig.9.

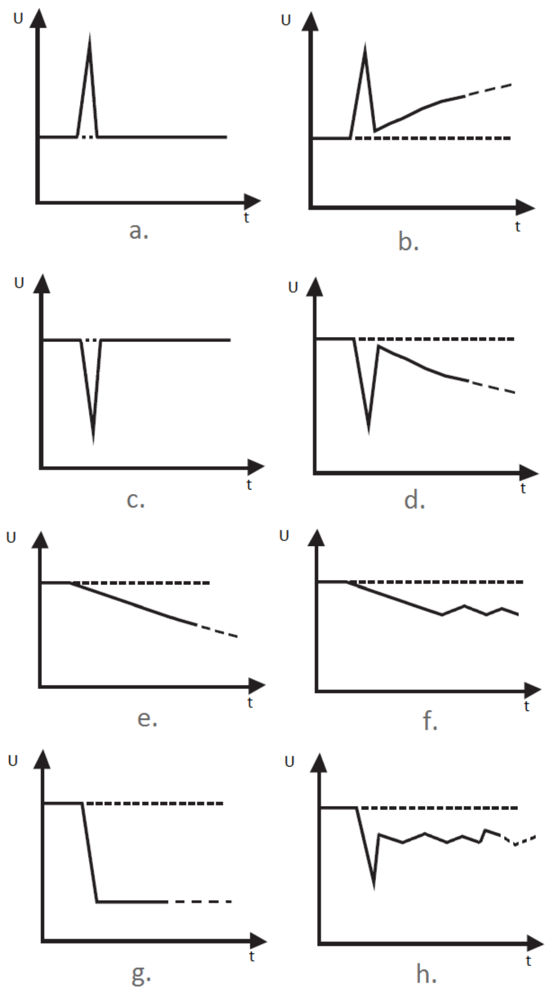


Figure 7. Possible faults of a power supply output:
a.) After a voltage peak, the output voltage returns to normal level;
b.) After a voltage peak, the output voltage stays high level;
c.) After a voltage drop, the output voltage returns to normal level;
d.) After a voltage drop, the output voltage stays low level;
e.) The output voltage continuously decreasing and stays low level;
f.) The output voltage continuously decreasing and gets unstable;
g.) The output voltage after a rapid drop down, stays low level;
h.) The output voltage after a rapid drop down, becomes unstable.

IV. CONCLUSION

In this paper, after checking the theoretical solutions, we have presented a useful real application. Valuable part of our work is, that we show the system component and programming solutions.

The redundant electronical solutions provides a consistent, reliable operation, by the cooperation of a micro-controller based embedded system. By the mentioned solution, the error-free running time can be increase.

We believe that the developed method can also use in other areas.

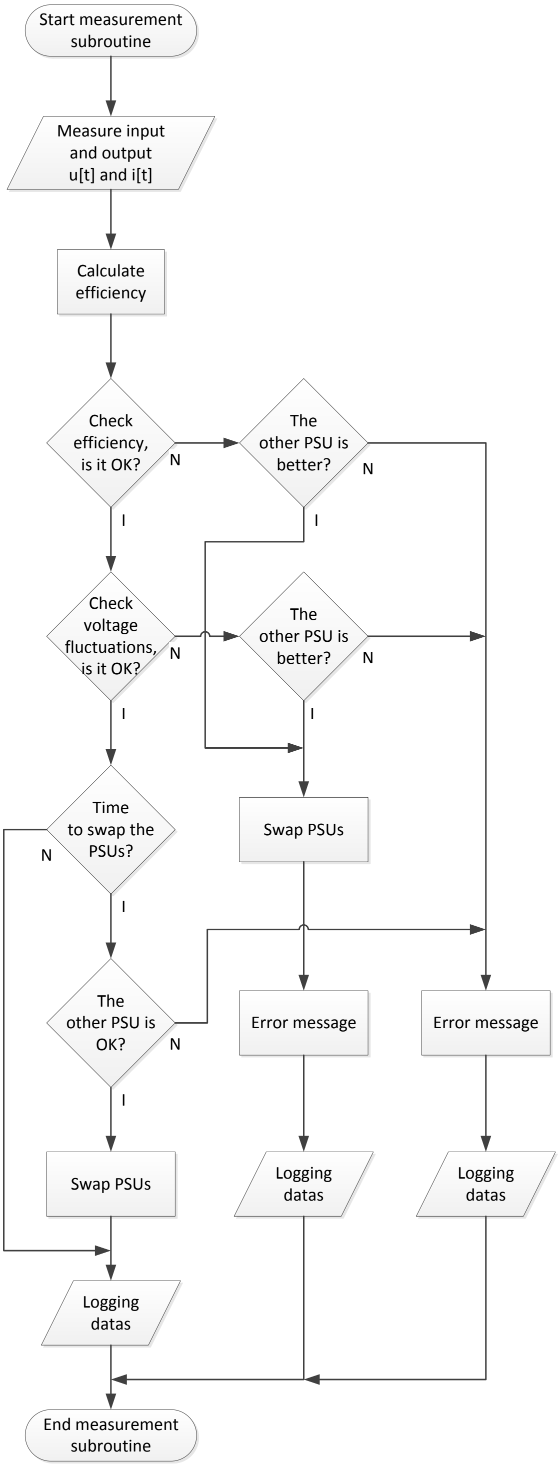
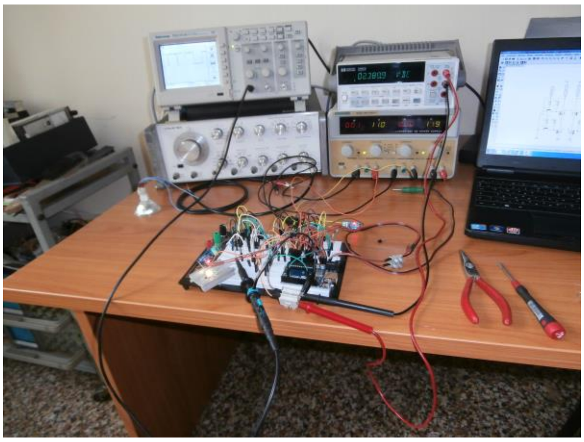


Figure 9. The flowchart of the monitoring program



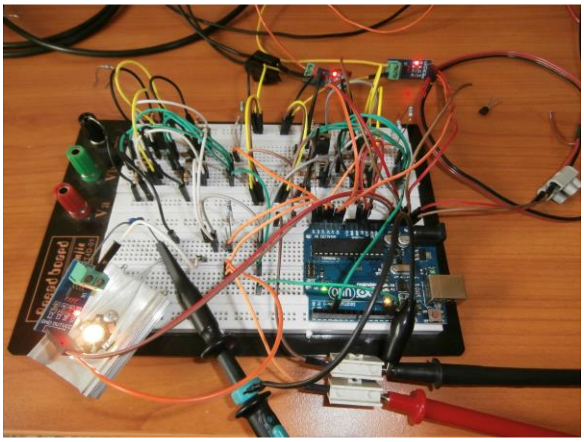


Figure 8. The development area and the model of the circuit

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