Concept of a Reliable Redundant Off-grid Power Supply Chain

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Abstract— **Electricity plays an increasingly important role in today's civil, industrial, medical and military applications. For optimal operation, it is essential to diagnose and the state of the device's power supply. In the case of an off-grid power supply system, it is required to check the status of all modules of the power supply chain. In order to ensure dependability, the redundancy of the power supply chain modules are needful, especially in critical applications. This paper proposes a microcontroller based embedded solution, which measures the different parameters of the distinct modules, and controls the redundant electronic units of the power supply line, to improve the reliability of the redundant off-grid power supply chain.**

I. INTRODUCTION

A fault-tolerant system would continue working even if the system suffers from some type of predefined failure. Handling of faults in critical and in non-critical systems are very similar. The fault-tolerant behavior is implemented into the system, as a combination of hardware and software redundancy. Reliability is something that must be "built in", not "tested in" [1].

In order for a circuit to indicate or predict an electrical malfunction, it needs to measure electrical parameters such as voltages versus ground potential, voltages compared to another voltage, temperature, etc.

From the firmware side, the time and the resources to evaluate the status of the device must be ensured. It is also a useful – in some applications an essential – feature, if the user can fine-tune the operation of the device.

I. THEORY

The stand-alone power system, is an off-grid electricity system, used areas that are not fitted with an electricity distribution system. It is include one or more methods of electricity generation and energy storage. Electricity could generated by the following methods: photovoltaic systems, wind turbines, geothermal sources, micro hydro systems, diesel or biofuel generators, thermoelectric generators. Energy storage is typically implemented as a battery bank.

A. Off-grid power supply

There are several applications where the electricity distribution system is not available, for example: environment monitoring systems, alarm systems, UAVs, military robots, etc. In an off grid system, the power supply solution would neither feed energy into the energy system nor
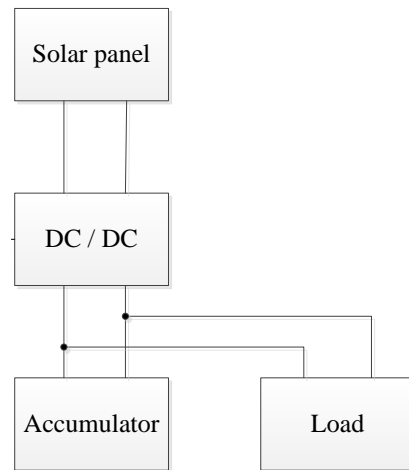

Figure 1.   Architecture of a solar powered, off-grid DC power supply system

extract energy from the energy system. We differentiate between DC and AC power systems depending on the transformation of energy. The proposed concept is usable in both cases. In this article the DC system is going to be discussed in more detail.

A solar powered off-grid system architecture is proposed in Fig. 1. The DC to DC converter contains the protecting elements and the measuring elements. However, in AC systems, instead of the DC/DC converter, an AC/DC converter could be found. [2]

The charge storage unit is the accumulator. The converter is mostly designed to charge a certain type of accumulator (different technologies have different charging diagrams and charging stages).

The quality of the converter significantly determines the capabilities and efficiency of the system. [3] Grouping could be further listed, but it would go beyond the bounds of this article, therefore we are confined to the most important ones.

The "Load" module in the first figure usually starts with a buck or a boost converter, to ensure the operating voltage level for the load of the system. In some cases it could also be a part of the DC/DC converter.

B. Redundant power supply

In duplicated PSUs (Power Supply Unit), there are a few important functions that should be implemented. The monitoring system – called PSU MCU (Power Supply Unit's Micro Controller Unit) in Fig. 2. – should be able

to establish electrical parameters of the different, individual PSUs. The monitoring system also should be able to notify the malfunctions of the PSUs. The power supply system should have the possibility to hot-plug-in the redundant PSUs, and provide continuous power supply conditions for the load. [4]

The switching matrix (SW in Figures) is used to modify the power line. It is controlled by the monitoring system.
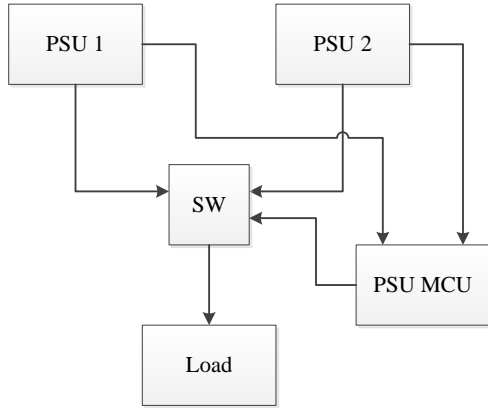

Figure 2.   A redundant, high reliable PSU based fault-tolerant system

II.   REALIZATION OF THE HARDWARE

A high reliable power supply can also be realized with redundant electrical modules or components – not just redundant PSUs. The concept of this solution can be seen at Fig. 3.

A.   Monitoring solar panels

The solar panel's input parameter is the sunshine. Therefore, it needs to be measured so that the panel can absorb the incoming energy. To the side of the device, a photoresistor was installed – with a glass cover – to make a reference parameter, [4]. It is good enough for a reference signal for the sunshine. It is also possible to compare the output power of the solar panels (in order to calculate it, it needs to measure the output voltage and current). After the calculations and efficiency comparisons, it is possible to decide whether the solar panel is defected – for example, broken – and needs to be replaced, or it is covered by something – for example, leaves – and needs to be cleaned.
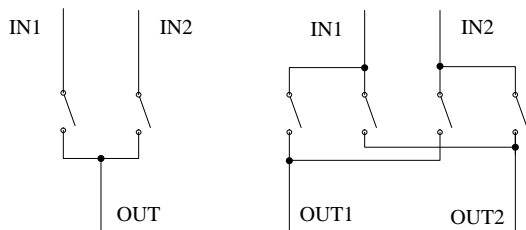

Figure 4.   Switching matrix module architecture:

a.) Two input to one output,
b.) Two input to two output.
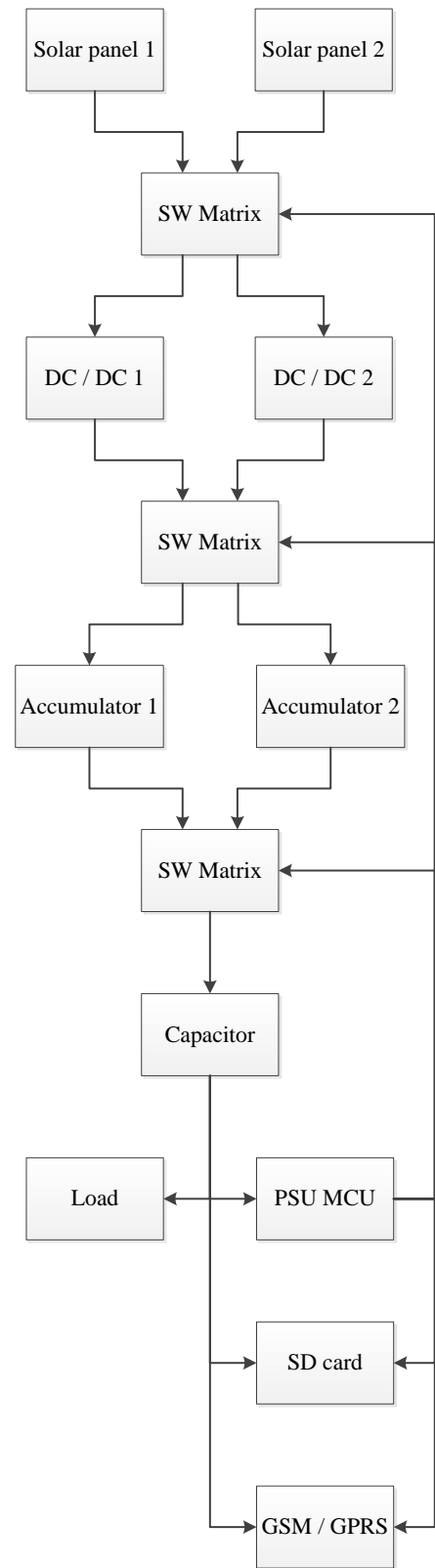

Figure 3.   Architecture of a high reliable, solar powered, off-grid DC power supply system

B. Switching matrix

The switching matrix contains semiconductor switching elements, MOSFETs [5]. They are easy to use and reliable components. MOSFETs are more reliable in DC operations than higher frequencies. The MOSFETs used in the switching matrix are more reliable – due to much rare switchover event – than, MOSFETs used in the DC/DC converters – in PWM switching mode. The architectural concept of the switching unit is shown in Fig. 4.

C. Electrical modules

The electrical parameters of each DC/DC converter module are measured [6]. The most important parameter is the efficiency of the modules. In order to calculate it, the module's incoming and outgoing power needs to be known. For that, the intensity of the input (I_{in}) and output (I_{out}) current must be measured and in addition to that, the input (U_{in}) and output (U_{out}) voltage must also be measured. In case of the converter module, the channel resistance of the MOSFET is also an important parameter to predict the remaining life time of the module. Over time, with usage and heat, the channel resistance of the MOSFET is likely to increase. Therefore, it may cause higher drain-to-source voltage (UDS), which might cause higher heat production. The concept of the measurement is shown in Fig. 5. It is important to use an insulated operational amplifier, since high U_{DS} voltages are a possible outcome.
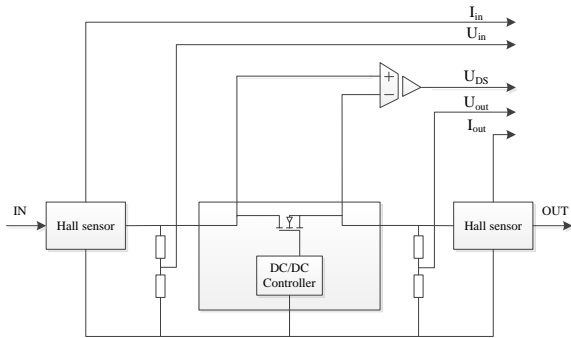

Figure 5.   The architecture of the measurement layout

At the testing operation, the aged channel resistance had been simulated by a serial, small milliohmic power resistor.

D. Accumulator

The accumulator stores the produced energy for the system. With aging, the inner resistance of the accumulator will increase and it will result in efficiency loss. This is measurable with the same principles and a similar mode which was showed in the DC/DC converter module [7].

E. Capacitor

In the power line, after the redundant accumulators, there is a two input one output switch. The switch is controlled in a way that the two accumulators do not cause short circuit to one another. At first, the actually running accumulator needs to switch off, and after a short period of time, the other accumulator has to switch on. In that short period of time none of the power sources are connected to the system, therefore the controllers could go to

brown-out, and other module's supply voltage could drop down [8]. In order to prevent this phenomenon, a 5.5V supercapacitor is built in and it stores adequate energy for the system, till the switching time.

F. Measuring and control system

The power supply's microcontroller works independently from the load's microcontroller. Its task is to monitor the modules, to search and detect faults, and to supervise the power supply unit [9]. To determine of the performance of the modules, the efficiency values are calculated. By looking at those values, different strategies such as either to swap the modules or to send error messages are decided.

The microcontroller is in sleep mode most of the time. The interrupt system wakes it up after a predefined time or after an external interrupt (Fig. 6). Some hardware-detected malfunctions can cause an external interrupt [10]. The error sensing system is prepared to recognize over current and current peaks, over and under voltages, voltage fluctuations, ripples, instabilities and no voltage outputs[11].
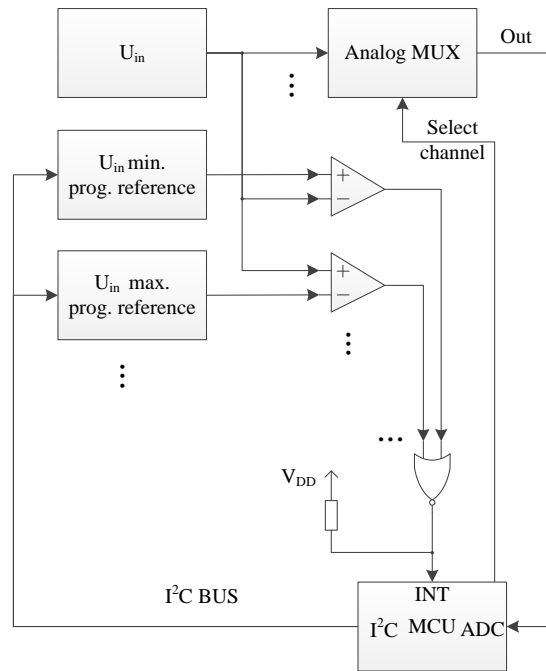

Figure 6.   The block diagram of the external interrupt system

All of the detailed settings are parameterizable by the user, differently for the different modules.

III.   SOFTWARE REALIZATION

From the software side, the user has multiple possibilities to adjust the working principles of the device. The user has the chance to decide what is more important. [12] If maximizing the lifetime – because the maintaining is hard, or it is difficult to access to the device – is the most important for the user, it is possible to activate the option of swapped running with hot-standby mode. It is also possible to choose the parameter from which the change depends on, for example: temperature of the critical components, the inner resistances or the drop-out voltages [13]. The user also has the possibility to adjust these parameters

[14] and to declare a hysteresis level for the measured variables.

It is also possible to choose load-sharing mode. In this mode both of the modules are used simultaneously, with under 50% of the maximally allowed load [15]. If one of the modules is detected as a defective module, the other one would take the entire load. In this case, the remaining module is working near to their maximal load [16]. The maintaining time is close, the failure of the remaining module is also expected [17].

The third option is to keep it running continuously from one module until it has got defective [18], after that swapping the task for the backup module [19]. With this solution it is also important that, the modules need to be monitored from time to time [20]. The monitoring task can be done by an artificial load [21] (preferably with an electrical load), or with swapping the modules for a short period [22] (just for heating up or just until the time of measurement).

The different closable working principles are showed in Fig. 7.

CONCLUSION

In this paper, firstly theoretical solutions have been mentioned. Then, a useful real life application about a redundant power supply unit has been presented. This adaptive and robust solution has been prepared for error prediction while increasing the error-free running time and strongly decreasing the maintaining time.

The individual and redundant power supply units provide a consistent, reliable operation. The cooperation between the modules is endured by a micro-controller based embedded system.

The error sending module is built-in with the communication module. Its task is to ensure the communication channel between the device and the operator, maintenance or supervisor system.

We believe that the proposed solution can be useful for civilian and industrial applications, where reliability is hardly required, even if it is needs some extra hardware and software redundancy.

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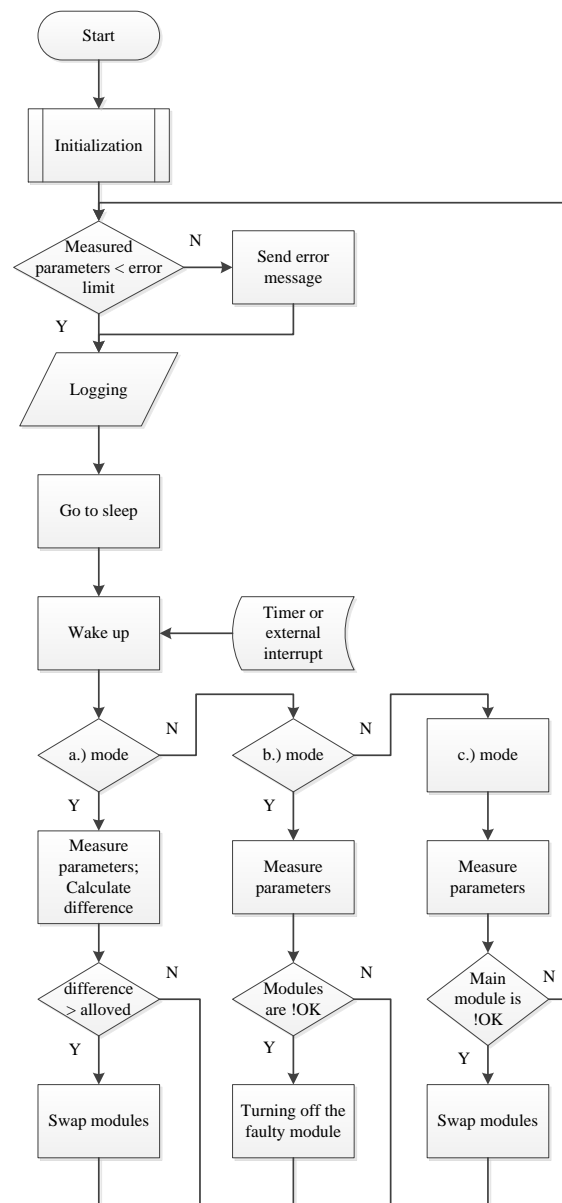[6] Györök György. Programozható analóg áramkörök mikrovezérlő

Figure 7.   Flowchart of the operating principle of switching to the backup module:

a.) Swapping after a predefined difference in hot-standby mode,
b.) Continuous running in load-shearing mode,
c.) Swapping to the backup module after the failure of the main module.

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