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Hybrid Backup Power Supply For Telecommunication Systems Based on Fuel Cell

Nikola Jovalekić, Miroslav Lazić and, Boris Šašić

Abstract: Telecommunication network nodes located at very hostile environments require, among other rigorous demands, highly reliable backup power supplies. Current solutions, which are mostly based on diesel generators, have several drawbacks such as unreliable start of a diesel generator at low temperatures, maintenance of the generator due to rotary parts, and the pollution of the environment which is caused by exhaustive fumes from a diesel engine. This paper proposes the implementation of backup power supply based on proton exchange membrane (PEM) fuel cell and solar panel. In addition, it is also depicted the implementation of high-efficiency boost converter which provides adequate supply voltage for telecommunication devices. The benefits of the proposed solution are improved energy utilization, decreased need for maintenance and zero emission.

Keywords: Hybrid backup power supply, fuel cell, high-efficiency boost converter, solar panel.

1 Introduction

Current solutions of backup power supplies in telecommunication network nodes are mostly realized using diesel generators and lead-acid batteries as energy storage [1]. When electric grid fails, node continues to be powered directly from batteries until the generator achieves the steady state and provides adequate voltage supply for the node; from that moment, batteries are charged again and the complete power supply is provided by a diesel generator. When electrical grid recovers from a breakdown, diesel generator stops and electrical grid becomes primary power supply again. Block diagram of the described system is given in the Figure 1.

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N. Jovalekić and M. Lazić are with IRITEL A.D. Institute, Batajnički Drum 23,11000 Belgrade, Serbia (e-mail: [n_jovalekic, mlazic]@iritel.com). B. Šašić is with Spellman High Voltage, 475 Wireless Bvld. Hauppauge, New York, USA (e-mail: BSasic@spellmanhv.com).

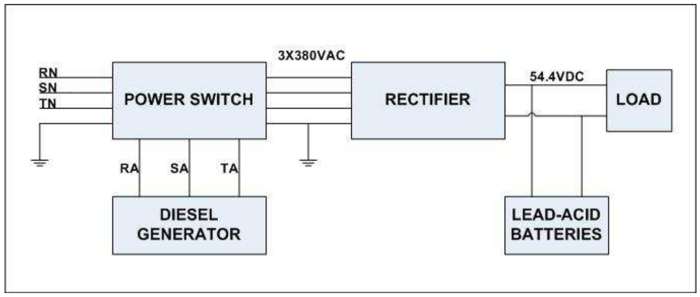

Fig. 1. Block Diagram of Backup Power Supply Based on Diesel Generator

In practice, this solution faces several problems, particularly if it is applied in the telecommunication network nodes in harsh environments.

The major difficulty is starting the diesel generator at low temperatures [2]. It requires warming up some of the parts of the generator, as well as preserving the diesel fuel from freezing. The reliability of such solution can be an issue due to poor weather conditions. In addition, the node can be completely unapproachable during the winter even by a helicopter if the winds are strong. In that case if the backup power supply fails, traffic loss can produce significant losses of profits of a telecommunication company. Another important issue is maintenance of a generator due to rotary parts [2]. Maintenance should be done at regular time instances for the purpose of proper operation, but, however, it is not always possible to maintain generators at equal time instances, because of weather conditions. On the other flip, pollution caused by exhaustive fumes from a diesel engine emerges as a burgeoning problem, and thus has to be considered adequately. Besides the environmental issue, efficiency of a diesel generator is smaller in comparison to systems that utilize fuel cells. Our motivation for the suggested implementation was based on the following demands:

- how to improve reliability and efficiency of the backup power supply system in the comparison to current solutions based on diesel generators
- how to reduce pollution that diesel generators produce

Proposed solution deploys fuel cell and solar panel to tackle the problem. Besides zero emission, offered implementation increases the reliability of the system as well as its efficiency.

2 Selection of the Fuel Cell

Today commercially available fuel cells can be divided into several groups, depending on parameters considered [3]. One of the divisions of the fuel cells could be:

- Direct Methanol Fuel Cell
- Proton Exchange Membrane Fuel Cell
- Alkaline Electrolyte Fuel Cell
- Phosphoric Acid Fuel Cell
- Solid-Oxide Fuel Cell
- Molten-Carbonate Fuel Cell

The main criterion for choosing the type of fuel cell for the proposed solution was the typical power consumption of telecommunication nodes that we considered. On the other side, another important factor was the operating temperature of the system, as well as its cost. Direct methanol fuel cells cannot be used because of several reasons. Firstly, they are intended for low-power consumption systems such as portable electronics [3]. Here should be pointed out that they have high energy density, but low power density on the other side. In other words, they are intended for systems that consume few watts of power in an extended period of time. Secondly, their efficiency is larger than diesel generator, but still significantly smaller than proton exchange membrane fuel cell [4]. The next mentioned type of fuel cell, alkaline fuel cell, nowadays has mostly historical value. They were used in the space program in the very beginning, but they are replaced with PEM fuel cells later on. Their main drawbacks are reliability, safety, ruggedness, and ease of use [5]. Phosphoric, Solid-Oxide, and Molten-Carbonate fuel cells are usually used in combined heat and power systems, designed for high power applications and are not suitable for the target power system [6].

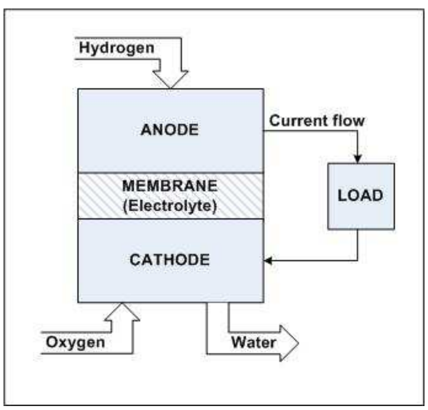

Fig. 2. Block Diagram of a PEM Fuel Cell

Proton Exchange Membrane fuel cells in an effective manner meet the power consumption criterion for 5kW telecommunication network nodes, as well as the operating environment. The electrolyte used is an ion conducting polymer, which operates at low temperatures, and provides the fast and reliable start of the cell [4]. These facts are very important, because when the regular power supply fails, the whole node is supplied from backup batteries until the fuel cell start. Because PEM fuel cells can be fully operational in less than 15 seconds, the solution does not need high capacity backup batteries. On the other hand, the absence of rotary parts and corrosive fluid hazards extends their operational time and reduces the need for maintenance. Finally, they can operate in any orientation due to solid state electrolyte and are suitable for various installing positions. A block diagram of a PEM fuel cell is given in Figure 2.

3 System Description and Results

The system is based on the PEM fuel cell that is primarily used to replace diesel generator in the backup power supply system. Besides PEM fuel cell, backup power supply system includes solar panel that can be used also as a primary source of energy. Block diagram of the system is given in Figure 3.

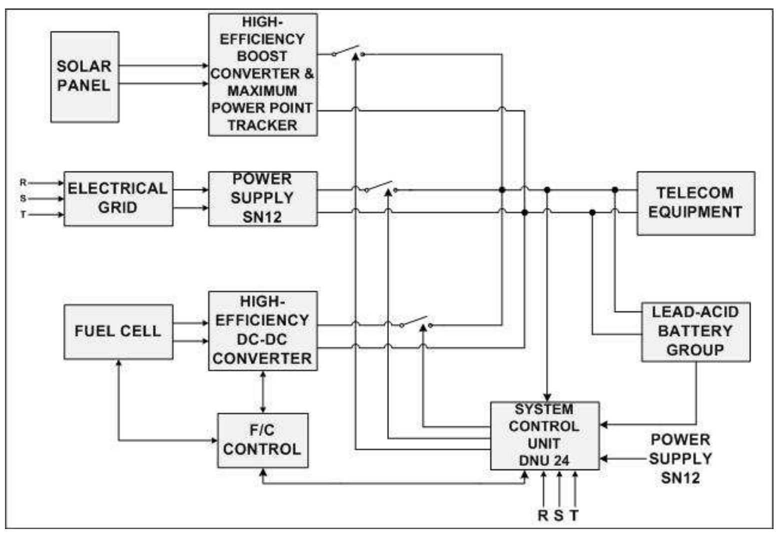

Fig. 3. Block Diagram of the System

The system control unit, DNU24 has been developed to provide monitoring and switching between sources during the operational time. Its main task is to monitor voltage and current rates of power sources, as well as rate of charging current of lead-acid batteries. Furthermore, it controls the sources and executes the decision algorithm for choosing the adequate primary source. The algorithm provides maximum energy efficacy by deploying solar panel whenever it is possible. On the other hand, when the energy from solar panel is unavailable, energy from electrical grid is deployed if its voltage is stabilized for at least one period of integration. The period of integration can be manually set, but, however, default value is 15 minutes. Fuel cell is deployed only in case when energy from solar panel is unavailable and electrical grid fails [7]. When electrical grid recovers or energy from solar panel becomes available again for at least one period of integration, fuel cell is not any more primary energy source. The flow chart of the decision algorithm is given in Figure 4.

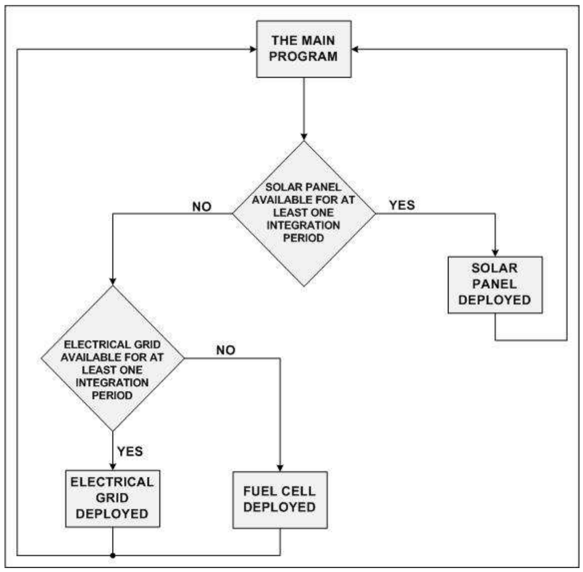

Fig. 4. Flow Chart of the Decision Algorithm

The DNU24 also enables the communication with monitoring center by two paths: primary, which can be over Ethernet or dial up modem, and backup, through GSM network. Transmission paths are firstly tested and one is chosen depending upon the availability and the user selection. The backup path is automatically selected if primary fails. Default backup path is GSM network because the assumption is it will be operational even if the telecommunication network node malfunctions. The assumption is based on the fact that different mobile operator will be selected as a backup path. DNU24 also provides data from fuel cell, concerning hydrogen and oxygen pressure as well as actual state of lead-acid batteries. Moreover, DNU24 continuously captures data and gives possibility to be recorded. One cycle of switching to lead-acid batteries than charged by SN12, and captured by DNU24 is given in Figure 5 and Figure 6, respectively.

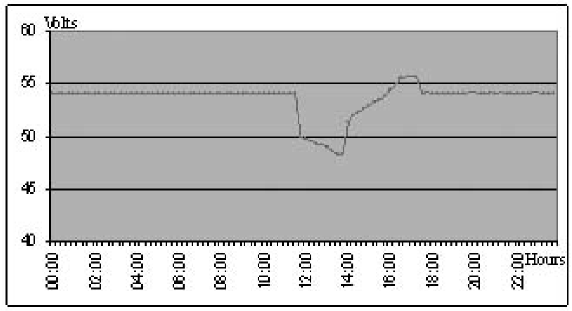

Fig. 5. Battery Voltage During the Transition Time

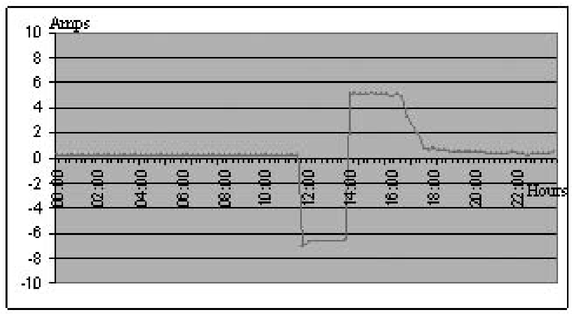

Fig. 6. Battery Current During the Transition Time

The SN12 rectifier is also controlled by DNU24. Its modular structure provides that nominal output power can be modifiable by adding or removing modules. When electrical grid is primary source of energy, the SN12 controls the charging of lead-acid batteries. Because it is very important that lead-acid batteries are charged according to their characteristics, SN12 is designed to charge batteries with constant current until the batteries reach the boost voltage. After that, batteries are charged with constant voltage. The characteristic of battery charging performed by SN12 is given in Figure 7.

Solar panel is chosen to be capable of delivering 5kW to both telecommunication devices and lead-acid battery group when the irradiance is 60% out of nominal value [8]. It is based on single crystal cells; additionally, high efficiency boost converter with maximum power point tracker enables the maximum efficiency at almost any rate of irradiance. The tracker is based on perturb and observe algorithm with improvement in respond to rapid changing of irradiance [9]. The electrical grid is normally deployed during the night or when the atmospheric conditions do not allow use of solar panel as the source of energy. In other words, solar panel and electrical grid are combined to provide the primary source of energy in the

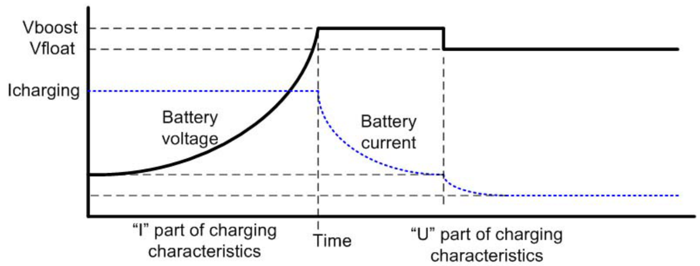

Fig. 7. Charging Characteristic of Lead-Acid Battery Performed by SN12

proposed solution.

The purpose of the fuel cell is to provide backup source of energy, when the electrical grid fails and solar panel cannot be used due to atmospheric conditions. In that case, fuel cell is switched to be the primary source of the energy providing nominally 8 hours of uninterruptible power supply. Fuel cell output voltage is regulated by a high-efficiency boost converter that provides output voltage and current regulation. A continuously variable control allows adequate power to devices and enables batteries to be fully charged. The input voltage can vary from 24V-36V, and nominal output power is 5kW. Topology of the boost converter offers high efficiency, due to its simple construction: during one switching period current flows only through one semiconductor switch or rectifier diode, thus minimizing the switching loses [10].

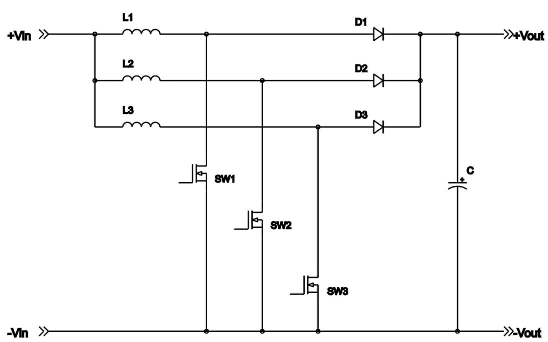

Fig. 8. Simplified Circuit Diagram of Three-Phase Boost Converter

The converter is realized as a three-phase topology. Each switch is driven by phase shifted signals for 120°, providing the effective switching frequency to be three times as fundamental switching frequency. On the other hand, a three-phase topology allows use of smaller inductances (in comparison to basic, one phase boost topology), hence producing lower rates of input current ripple which results in lower stress on output capacitors. Lower stress on output capacitors extends faultless operation of the converter and provides higher efficacy. A simplified circuit diagram of three phase boost converter is given in Figure 8.

The output voltage of converter is 54.4 volts; if open circuit voltage and minimal output voltage from fuel cell is considered, value of duty ratio must be 1/3<D<2/3. In this case, current ripple rising time, slope, and current peak are described by equations (1), (2), and (3), respectively [11].

$$t = (D - \frac{1}{3}) \times T \tag{1}$$

$$k_{in} = 2 \times (k_{on} - k_{off}) = 2 \times \frac{(V_{in})}{L_{in}} - \frac{(V_{out} - V_{in})}{L_{in}} \tag{2}$$

$$\Delta I_{in} = k_{in} \times (D - \frac{1}{3}) \times T = (D - \frac{1}{3}) \times (2 - 3 \times D) \times \frac{V_{out} \times T}{L_{in}} \tag{3}$$

The RMS value of output capacitor current when $1/3 < \mathrm{D} < 2/3$ is given in Eq.(4):

$$I_{CoRMS} = \frac{I_{out}}{3 \times (1 - D)} \times \sqrt{\frac{1}{3} \times (3 \times D - 1) \times (2 - 3 \times D)} \tag{4}$$

Waveforms of input current ripple and output capacitor current are given in Fig. 9.

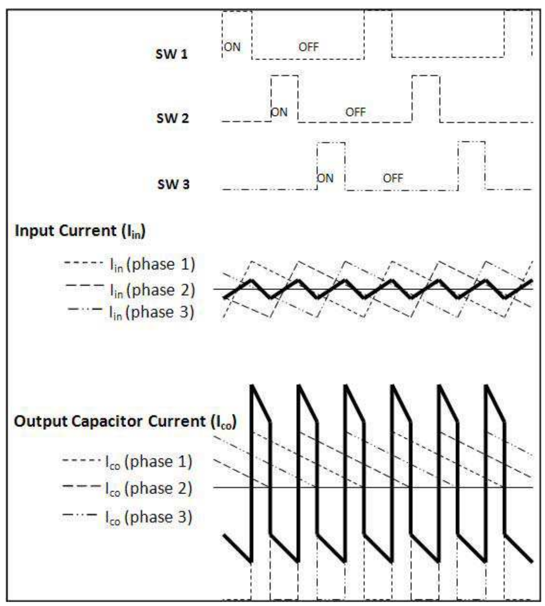

Fig. 9. Boost Converter Input Current and Output Capacitor Current

It can be easily viewed that resulting input current ripple is lesser than phase input current ripple. However, due to stress reduction on output capacitors, life cycle of the most vulnerable components of the converter is extended.

4 Conclusion

The depicted solution is based mainly on PEM fuel cell. The integration of the fuel cell in the system improves reliability of the system, and decreases the cost of implementation in the long run. On the other hand, use of fuel cell allows deploying a backup battery that has several times lesser capacity than that with diesel generator. Furthermore, operational time between two consecutive charging is extended and charging time in comparison with lead acid batteries is significantly shortened. The backup battery is only needed when switching between sources occurs and, hence, there is no need for high capacity batteries. Secondly, the start of a PEM fuel cell is not the time consuming operation, and it is not necessary to keep the fuel warm. Moreover, efficiency of a fuel cell can be up to 2.5 times higher than efficiency of a diesel generator and operational time can be further extended if tank with hydrogen is replaced by reformer. Solar panel enables significant energy savings as well as environmentally clean source of energy. Finally, proposed hybrid solution can give optimal results if reliability, cost, and environmental issues are considered.

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