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Applications of multiport converters

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Abstract – **In this paper are presented some applications of the multiport converters. The most significant examples from applications of the multiport converters presented in the literature are selected here from the following areas of usage: electric cars, energy generation systems from renewable sources, and microgrids for distributed generation. The objective is to shown that the multiport converters must be designed and then analyzed according to their area of applications. The simulation results shows how different multiport converters operate with more switching elements connected in series and parallel in order to assure the load demand based on available energy from the input sources and/or energy storage devices. The operating modes are analyzed based on different energy management strategies proposed here.**

Keywords - multiport converter, hybrid electric vehicles, renewable energy, energy storage devices

I. INTRODUCTION

The structure of the multiport converters can be: Multiple Input Single Output (MISO), Single Input Single Output (SISO) or Single Input Multiple Output (SIMO) type. The appropriate type of structure is chosen depending on the input data, respectively output data. By reducing the number of the components used in the hardware structures of the multiport converters, we are reducing also the cost of the system of generating energy.

DC/DC multiport converters are the perfect solution for all the applications that imply solving complex problems of distributing energy. DC/DC multiport converters are able to control more DC/DC converters of buck or boost type at a lower cost (condensers of output in a minimal number, power transistors and diodes of low costs, without different external sensors), however with a flow of big power, being ideal for many applications [1, 2, 3, 4]. By using a control unit of the intelligent power, the system offers a high tolerance regarding the values of the parameters to control, including a galvanic isolation of fuse of all the ports of high voltage. Each port of low voltage can be controlled easily in both voltage and current or power through graphical interfaces that communicate with the user via CAN communications. The individual inlaid stages of power for each port allow a low ripple of low voltage and for the current, when it is used with only one port. Besides, the levels of power necessary for the functioning of the multiport converter may be changed quickly and may be even hardware modified, by adding or eliminating the modules.

Operating the converter at high frequency decreases the converter volume and increases the power density of converter. However, increasing the operating frequency increases the switching losses and the Electromagnetic Interference (EMI) resulting reduction in efficiency of converter [5, 6].

The applications of the multiport converters can be:

- Electric cars;
- Hybrid power system;
- Systems of generating power from renewable sources;
- Micro networks of distributing the electric energy;

The way of functioning of a multiport converter with three inputs and an output is presented in the section II. At the same time, in this section a simulation of a multiport converter is presented. An optimal management of this kind of a system assumes a control of the inputs, respectively of outputs from the multiport converter and a decisional system on the base of the simplest and most concrete rules. This kind of management is proposed in section III of this article.

Section IV is focused on multiport converters topologies for microgrid applications. Last sections conclude the paper.

II. MULTIPORT CONVERTER FOR AUTOMOTIVE APPLICATIONS

The Hybrid Electric Vehicles (HEV) and the Electric Vehicles (EV) have become more and more popular comparing to the internal combustion engines, due to the minor impact on the environment, the reduced consumption of fuel and high efficiency. A combination of different energy sources such as: layer of batteries, ultra-capacitors, fuel cells and, more recently, solar panels, can be used to obtain high power and a density of high energy for the EV. Normally, a power system for an EV comprises a converter with multiple inputs and one single output. This converter manages the power flows among different energy sources and maintains DC bus voltage constant [7, 8, 9]. A system of MISO type that is able to manage three different energy sources is presented in Figure 1.

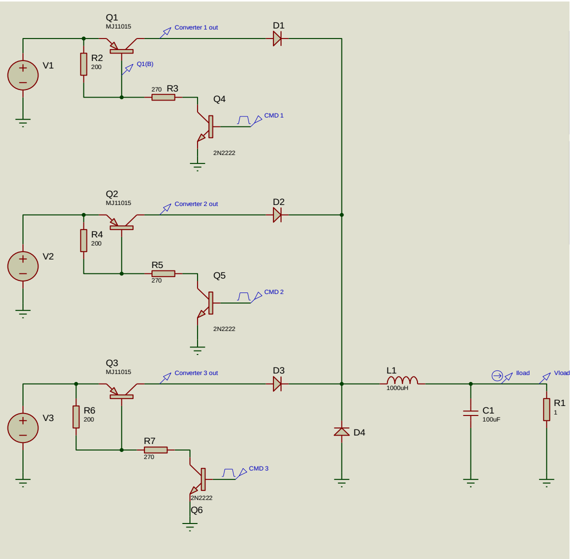

Figure 1. Topology of multiport converter with three different inputs

In order to see how a system like this is functioning, we simulated the electrical scheme, using ISIS Proteus. We considered that each source of voltage, V1-V3 has the nominal voltage of 48 V. The switching frequency of the power transistors are equal to the value of 10 kHZ. For the figures 2-4 the converters were controlled simultaneously, having a PWM duty cycle of 50%.

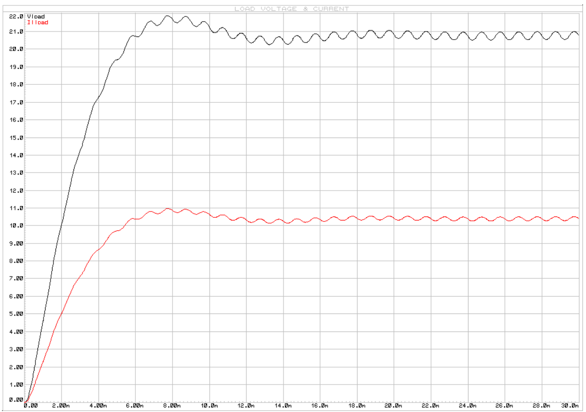

Figure 2. Voltage and current waveforms – operated only the convertor 1

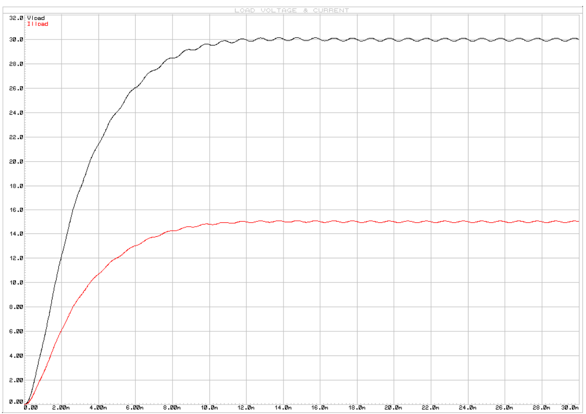

Figure 3. Voltage and current waveforms – operated converter 1 and converter 2

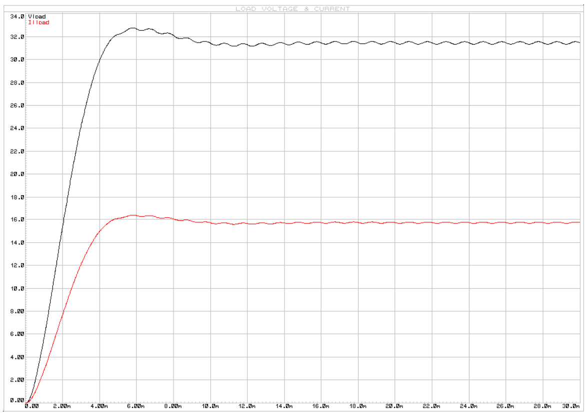

Figure 4. Voltage and current waveforms – operated all 3 converters

In order to see better the influence of each converter we operated them with a time lag, therefore the second converter is operated after 10ms, and the third one is operated after 20ms. The result of simulation is shown below:

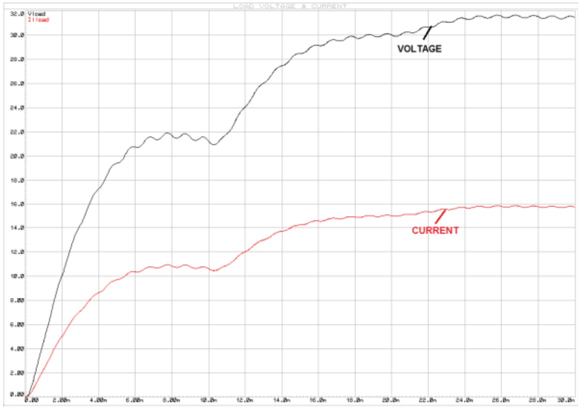

Figure 5. Output voltage and load current for the shifted command of the individual converters

In the case of this simulation the load was of resistive type with the value of 2 Ω. If the value of the load decreases to 1 Ω, the waveforms will become:

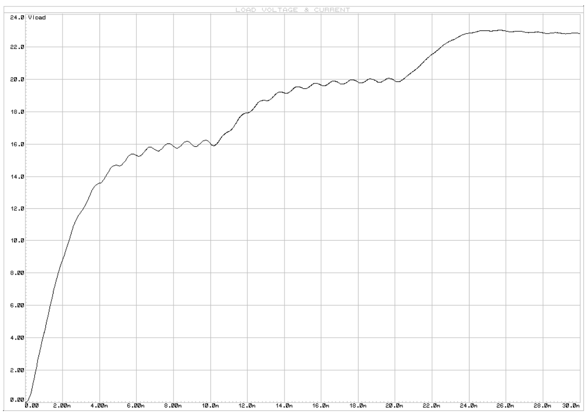

Figure 6. Load voltage for the shifted command of the individual converters

The converters were operated with a PWM duty cycle of 80% (see Figure 6). As the converters operate in a continuous current – mode (CCM) on a resistive load, the output voltage has a value established by the specific function of transfer for this drive. The losses of voltage are bigger in case of a current of a higher load, so the value of voltage on load decreases towards the values presented in Figure 5. If the DC load requires a fixed voltage, then a control of the PWM command is necessary. Depending on the error of the output voltage, can using a proportional-integrator regulator (PI).

There are many DC loads in the structure of a HEV or EV, thus more levels of output voltage are necessary. Usually, only one DC bus voltage is controlled (that of a higher power), from which, later, the levels of DC bus voltage of a lower power are obtained with DC-DC converter without control of the command coefficient.

The SISO converters are used in order to supply different levels of output voltage. On the other hand, a SIMO multiport converter which processes the power at a specific moment can supply different loads of DC [10, 11].

For the multiport converters we can use the power electronic switches of both unidirectional and bidirectional types, according to the customer's wish, taking into consideration the implemented requirements of the management strategy, the features of the electric loads and of the sources of energy, and the usage of some devices of energy storage. When a control of bidirectional type of the power flow is required, we will use bidirectional power electronic switches. As for the rest, in order to reduce the converter's cost, we will use unidirectional converters [12]. The duty cycle for the power electronic switch can be reduced when the number of inputs or outputs increase, the output voltage can be regulated both at a higher level than that of the input (using the converters of boost type) and at a lower level than the input voltage (using the converters of buck type).

An example of a conversion system of power for EV is presented in Figure 7.

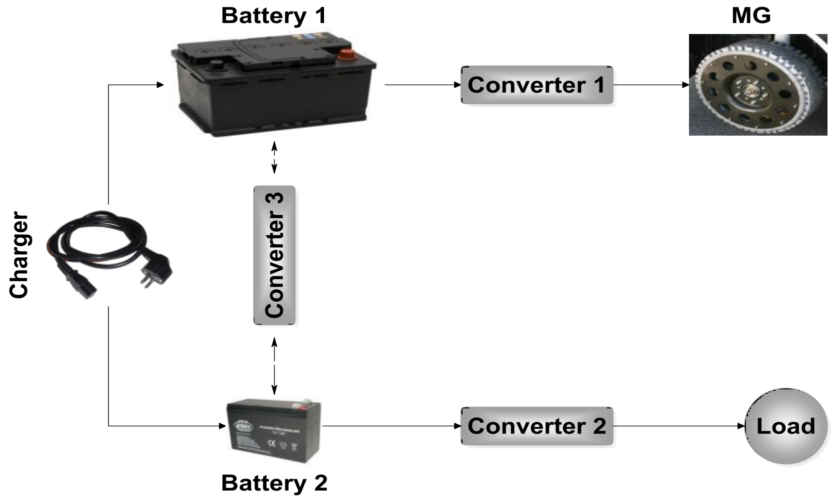

Figure 7. Conversion system of power for EV

In this example, there are two electric loads and two batteries, which are interconnected through three converters.

The system is composed of:

- An MG (motor generator) general engine;
- A battery of high voltage and high capacity Battery 1 for the traction engine;
- A battery of low voltage Battery 2 – used as a source of supply of the command and control circuits;

Depending on the EV type, the voltage of Battery 1 is between 100-500V. The Converter 1 is connected between the Battery 1 and the MG traction engine, in order to increase the efficiency of the engine and to control its performances. In a similar way, Converter 2 is connected between Battery 2 and Load. This load can be represented by actuators. In addition, a DC/DC converter 3 is attached connected between the two batteries for the hardware redundancy of the system. In the case of electric vehicles there is one more converter use for charging the two batteries – Charger.

III. MULTIPORT CONVERTERS FOR HYBRID SYSTEMS BASED ON RENEWABLE ENERGY

Figure 8 represents a diagram of block of a hybrid power supply system, which requires three power generators: wind generator, photovoltaic panels and hydrogen fuel cells. This system is divided into seven blocks. The first block represents the wind generator, the second one the solar generator, and the third one is the fuel cell generator. The AC/DC block converter transforms the alternative current energy generated by the wind load into continuous current energy. The multiport converter block is effectuated by a MISO converter with three inputs and one output. If we want to charge the alternative current loads, we will make a connection between the load and the output of the multiport converter into an inverter block.

Depending of the power generator's operating conditions we gain power at the output system. For each of the energy loads we have considered a nominal value. If the Voltage of the loads is lower than the proper nominal value, then the loads will not be connected at the multiport converter input.

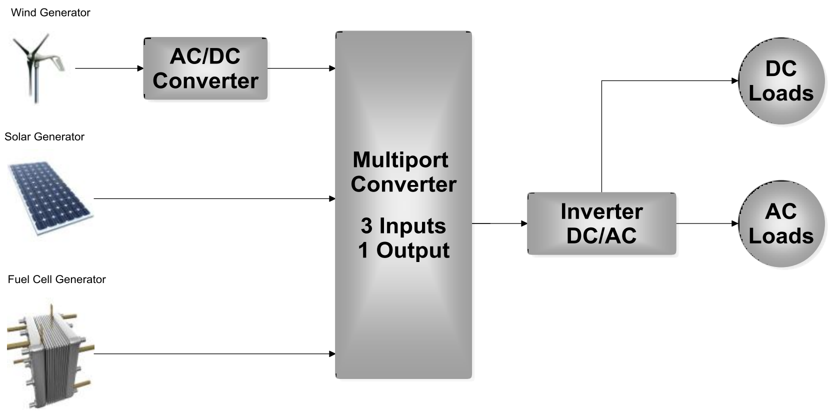

Figure 8. Hybrid power supply system

In table 1 we can observe the loads connection mode, considering "1" for connected and "0" for unconnected.

Table 1. Hybrid power supply system connection mode

Operating Mode	POWER GENERATION SOURCES			Load
	Wing Generator	Solar Generator	Fuel Cells	
Mode 1	0	0	0	0
Mode 2	0	0	1	1
Mode 3	0	1	0	1
Mode 4	0	1	1	1
Mode 5	1	0	0	1
Mode 6	1	0	1	1
Mode 7	1	1	0	1
Mode 8	1	1	1	1

The software diagram related to table 1 is presented in figure 9.

The management system reads continuously the voltage values of the three power generator sources and depending on the established nominal values for each source, it connects or disconnects that source at the multiport converter input.

The connection criteria are that the source voltage should be higher than the nominal voltage. To avoid the continuous connection/disconnection process that is around the nominal value with high frequency, we have considered a 0.5 V hysteresis for each source. By a nominal value of the voltage of the energy source, we understand a chart with the optimal values, depending on the operating conditions of the source, supplied by its manufacturer.

IV. MULTIPORT CONVERTERS FOR MICROGRID APPLICATIONS

Electrical networks that are smartly distributed could provide the platform for the usage of the renewable energy source for metropolitan areas and could provide protection if some disturbances may occur in the interconnected power systems, caused by, for example, natural calamities, giving the possibility of dividing into independent micro networks.

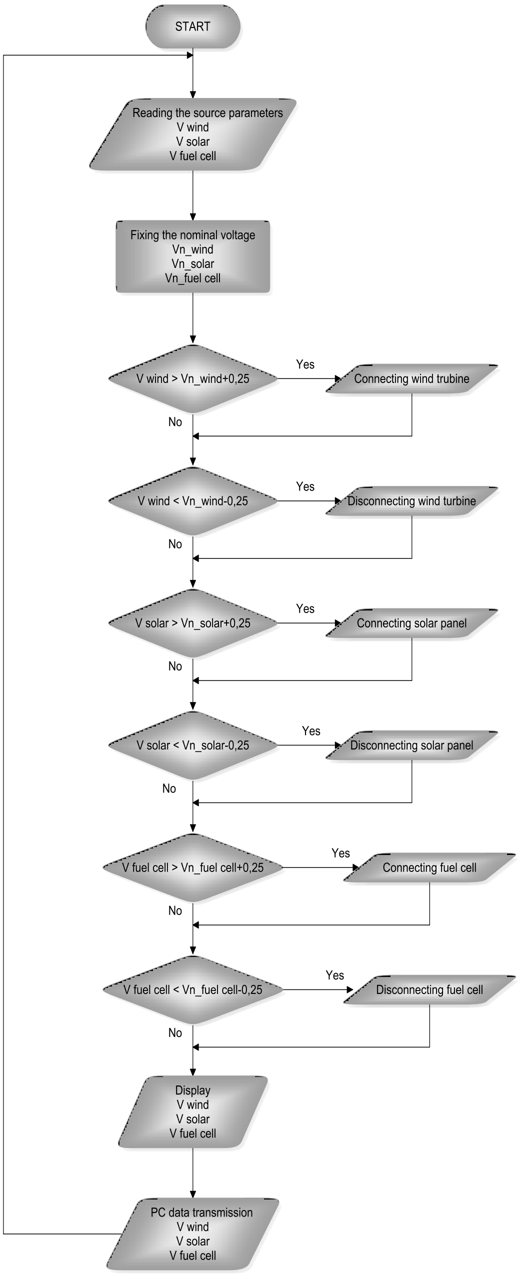

Figure 9. Software diagram of the hybrid system control

Figure 10 represents an architectural model with an intermediate bus of direct current (DC) using renewable sources which enclose fuel cells (FC), wind turbine, solar panels, micro turbines, storage energy systems, AC/DC converters and AC/AC [13,14].

The Distributed Generation units (DG) are parallel connected, and the DG system can operate independently or in parallel with a local AC network. If we combine the use of the renewable power supply with Un-interruptible Power Supply (UPS), the resulting architecture will provide the system with increased security and concurrently it will isolate the load from the UPS output against possible disturbances. Although, the stability and the security of the output UPS load cannot be secured in total.

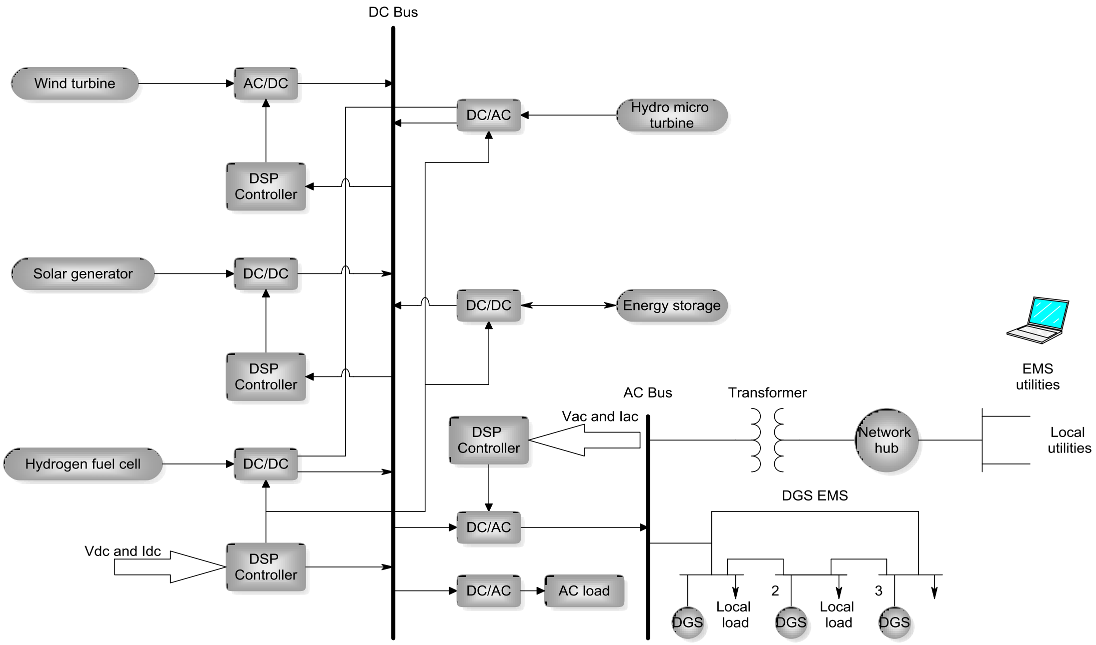

Figure 10. Bus architecture of DC for energy generation system using renewable sources (adapted from [10])

A multiport converter structure used for the connection of an AC load at an AC local network, charged from renewable sources, it is being proposed in the following figure:

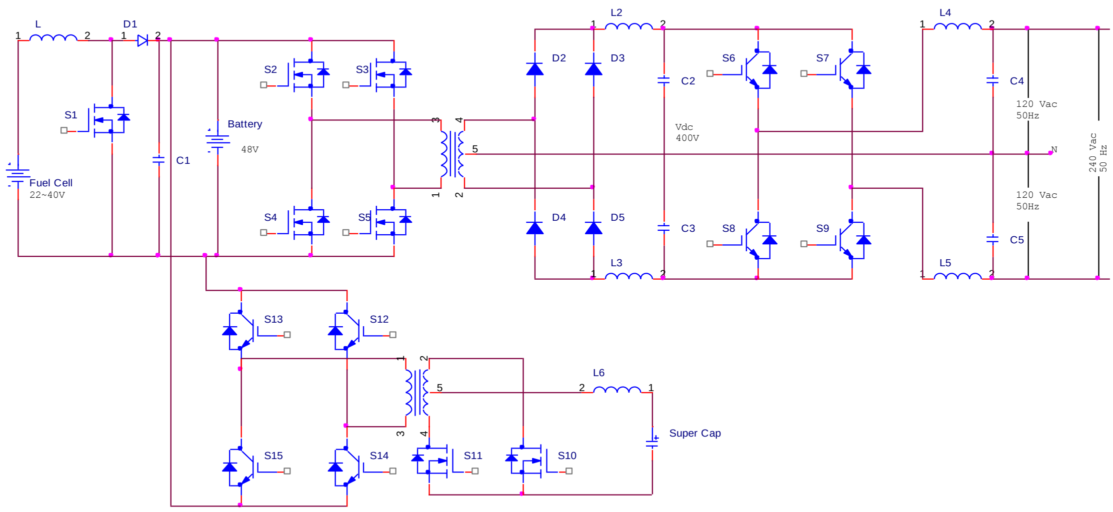

Figure 11. Multiport converter topology charged with renewable sources (adapted from [10])

The structure comprises:

1. Power source - fuel cell;

2. Energy storage devices - batteries and super capacitors;

3. Boost DC-DC converter used for fixing the voltage provided by the fuel cell;

4. Bidirectional DC-DC interface converter between the DC bus (low level - DC low) of the accumulator batteries and the ultra-capacitors layer;

5. Full bridge DC-DC converter uses a HF transformer for raising the voltage of the lower DC bus voltage at the level voltage of the high voltage DC bus, assuring in the same time the correct electrical isolation. The primary coil is reversed by the IGBT bridge and the voltage beats from the secondary coil are rectified by a bridge of fast diodes and filtrate LC;

6. The output DC-AC converter (inverter) has the role to generate the alternative voltage which is used by the alternative current users. If we have an excess of energy, a part, or even all of it, can be transferred to the local network using the same inverter.

V. CONCLUSION

In this paper a couple of multiport converter applications were presented. Definitely, the applications can be multiples, but here three applications from following topics are selected: electric cars, energy generation systems from renewable sources, and microgrids for distributed generation.

The MISO, SISO or SIMO multiport converters topologies may be used, depending of the number of input energy sources and loads. Usually, an energy storage device or a hybrid topology based on many storage technologies is used. Thus, the design requires a number of switching devices. This number must be minimized to reduce the costs for the topology used.

For example, the simulation made for a MISO multiport converter topology with three inputs and one output shown that operating modes are selected by the switching commands based on an appropriate energy management strategy, which will assure the load demand from the energy sources. If all input sources could generate energy, then all three sub-converters will be simultaneously activated to assure the load demand. The surplus of energy will be stored if an energy devices is used. A simple control algorithm was analyzed in section III for optimal energy management of the MIMO multiport converter. The efficiency of the energy strategy proposed is shown by simulation in different operating modes. Considering its simple implementation into microcontrollers, the price of the entire conversion system could be competitive with other solutions proposed.

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