Mechatronic System for Energy Efficiency in Bus Transport

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***Abstract*— Green transport for improving air quality is essential and urgent goal for reaching a healthy environment. In towns with large fleets of public vehicles, technology transfer from standard into new and better solutions requires, in general, time and great investments. This paper presents a quick retrofit for conventional buses in urban transport in order to reduce fuel consumption by using photovoltaic (PV) panels that only recharge the original bus batteries. Experimental tests show that this solution is really effective. Indeed, it could save, per year, several hundred liters of diesel fuel for each bus after considering a solar energy production of about 1.4 MWh.**

***Index Terms*— PV panels, batteries, energy efficiency, urban transit**

I. Introduction

Generally, research almost focuses on new and future products. But, nowadays some issues like environment pollution requires also immediate solutions in order to improve sustainability of life. For instance, urban traffic are actually responsible for 40% of CO_2 emissions from road transport in Europe [1]. Large bus fleets for public transportation still have a great part of their vehicles using diesel motors. New electric and hybrids vehicles are now produced, but full transition from current to new technologies (e.g., bio-fuel, ultracapacitors, etc.) is still a long-term plan. In fact, great investments are also required. In any case, fuel economy is a must for air quality and, therefore, short-term solutions for achieving green transport are also searched.

This paper presents a quick retrofit as a solution for conventional urban buses by using PV panels on the roof for recharging the original batteries instead of using an auxiliary one.

Garner [2] analyzed the application of solar vehicle roof about twenty years ago, but using a separate battery. After some prototypes and studies during the years, nowadays cars with convex solar roof for internal ventilation are even produced in series. In Europe, electric buses for public transit are mostly traditional trolley bus. However, fully electric vehicles have been introduced in various bus fleets. In general, new high-tech eco-buses are now in service around the world. For instance, since 2008, electric buses powered by capacitors and also lithium batteries are in service in Shanghai (China).

A few electric solar-charged buses also exist. Nevertheless, about solar buses, mainly prototypes have been realized until now and using auxiliary batteries. Starting from 2012, the IEEE International Electric Vehicle Conference will be organized and therefore a more rapid development, even of solar vehicles, is expected in the near future.

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II. The SIMEBUS system

In a conventional bus, electrical power generation is provided by one or more alternators. They take 8÷10 kW of mechanical power, which corresponds to 8÷12% of the fuel engine power, in order to transform it in electricity with an average efficiency of 30÷40%. Energy is then stored in a lead-acid battery so that it is returned with an average efficiency of 70÷80% to the continuous loads (e.g., on-board lights) and of 60% to impulsive loads (e.g., door openings). However, frequent bus stops in urban mobility decreases alternators efficiency so that the energy stored in the batteries is not always sufficient to meet all the loads.

The proposed system, which comes from an industrial project called SIMEBUS, contributes to recharging the on-board original batteries in order to keep them ready to supply energy to the electrical circuits (i.e, lights, ventilation, etc.) during the normal bus service or daily cleaning activity. In this way, the alternators have a reduced activity for the same aim and therefore a fuel economy is achieved. Figure 1 shows a diagram of the system architecture.

SunPower 220Wp Black PV modules have been used in the first of the two planned prototypes, here described. Their efficiency is 17.7%. As known, the optimal working point of a PV panel is defined as Maximum Power Point (MPP) that depends on some environmental parameters, like solar irradiance and temperature. In urban mobility, a bus is subject to sudden and different shadowing conditions. In these cases, either partial or full shadowing of a panel leads to a change of its MPP and therefore to power loss. The SIMEBUS system adopts the National Semiconductor SolarMagic^{TM}technology [3], whose MPP tracking (MPPT) controller has a fast response time for

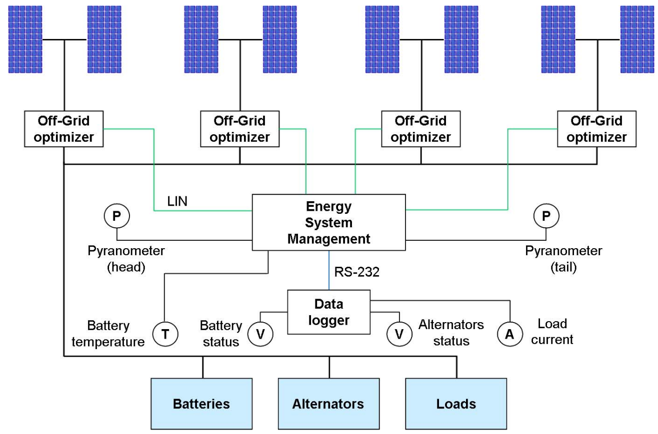

Fig. 1. The SIMEBUS system architecture

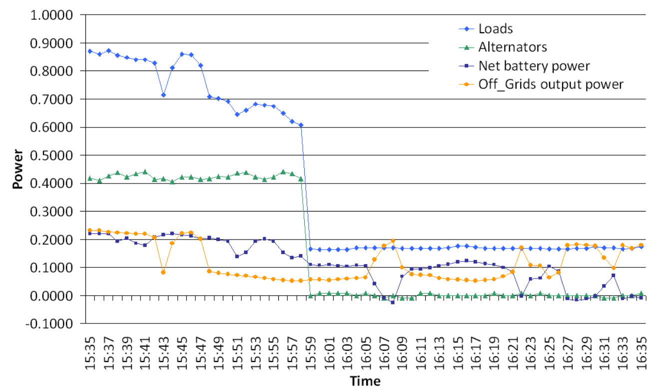

Fig. 2. SIMEBUS system power balance

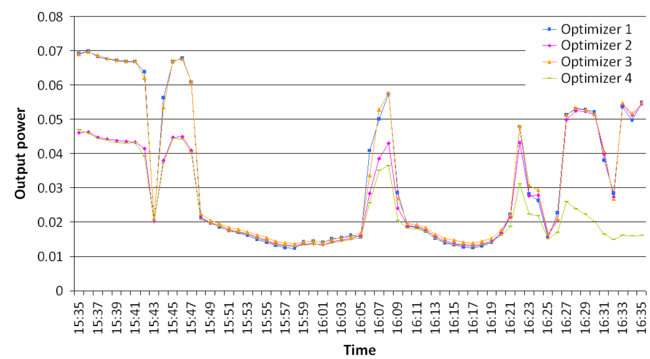

Fig. 3. PV system output power

rapid changes of the MPP, in order to recover up to 71% of the lost output power.

Indeed, this technology is included in an Off-Grid Optimizer, a device that includes a microprocessor for panel control, programming and management of the battery charging profile, and even data collection. This device can work up to 600W@24V or 300W@12V of peak power.

The SIMEBUS system provides four Off-Grid Optimizers (i.e., in a distributed architecture, one device for every two panels), which are directly supplied by the PV modules. Each Off-Grid provides information on various parameters through a Local Interconnect Network (LIN) bus. A tele-management subsystem allows remote monitoring of the PV modules status and of some environmental conditions (e.g., solar irradiance). In fact, two pyranometers are fixed on the bus roof, one at the head and the other at the tail.

Through an RS-232 line, data are then sent to a single on-board data logger for analysis and back-up. It also reads load currents and the batteries and alternators status.

The whole system allows obtaining two main benefits:

1) reduction of the fuel consumption
2) motor turn-off during long bus stops (e.g., terminal), but with the auxiliary services on.

III. Experimental Results

The SIMEBUS system has been applied to an Iveco CityClass-Mod.491.12.27 bus with two lead-acid batteries (12V 220Ah each) and two alternators (120A and 55A respectively).

Figure 2 reports, in normalized form, the power balance for the whole system after considering a 60 minute test period, whereas Figure 3 reports the output power of the PV system only.

This system can produce, under typical weather conditions in Turin (Italy), about 1.4 MWh per bus in a year, which are equivalent to about 750 liters of diesel fuel. It means that, if considering a fleet of 500 urban buses, this system could allow a reduction, per year, of about 650 tons of carbon dioxide (CO_2), 200 kg of particulate matter (PM), and 3.5 tons of nitrogen oxides (NO_x).

IV. Conclusions

A mechatronic system for improving the energy efficiency of traditional diesel-motor buses has been presented. It considers application of PV panels on the vehicle for recharging the original chemical batteries.

After first tests, results show that this solution, to quickly retrofit buses, could improve air quality in urban areas by saving, each year, several hundred liters of fuel per bus and, accordingly, leading to a remarkable greenhouse gas emission mitigation.

Next step is to achieve solutions for disabling one of the bus alternators by supplying more energy using novel solar panels, now under test, with higher efficiency.

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