Optimal route scheduling-driven study of a photovoltaic charging-station (parking lot) for electric mini-buses

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Abstract: The objective of the present study is threefold: To highlight how electro-mobility can: (a) Contribute to the promotion of the environmental conservation of the rural areas (through an integrated solution for reducing the carbon footprint of road facilities and transport), (b) Enhance tourism-based economical development, (c) facilitate students in their daily transport and residents (elderly, disabled, distant-residents) in their daily on-demand transport. The overall goal is to design an energy-efficient, regional intelligent transportation system with innovative solar-energy charging-stations for e-vehicles in municipalities with many geographically scattered small villages and small cities. The innovative character of the study is that it tries to tackle all three specific objectives simultaneously and with the same means, since it utilizes Intelligent Transportation Systems (ITS). The study is adapted and applied to an area with the above characteristics, in order to demonstrate the proof of concept.

1. Problem description

The Western Macedonia Region offers a great number of tourist attractions; therefore, an intelligent network of electric mini-buses will bring added-value to these attractions. Additionally, a cross-border interconnection of these touristic sites can be enhanced by a regular cross-border route of a “touristic electric mini-bus”. Such an electric mini-bus interconnection can facilitate tourists and the local population to identify many cultural common characteristics between the Western Macedonia region and the neighboring country (FYROM).

Moreover, especially in Prespa Municipality, which consists of small and district residential areas (villages), students have to use “traditional/conventional” public transport or taxis in their daily trip to school. Replacing the current transport modes with more energy-efficient ones within a regional intelligent transportation system will support the efficient realisation of both the tourist promotion of the area and the students’ daily transportation.

Furthermore, due to the heavy winter periods, residents in this region, and especially elderly, disabled, distant-residents, face great difficulties in their daily transport. This concept faces this challenge and facilitates residents in these Municipalities with the on-demand use of utility electric vehicles (e-vehicles).

The concept is compatible with the broad EU energy policy context such as Climate-Energy packages,
Energy Union and decarbonisation of transport, since it creates synergies between Renewable Energy Sources, electricity grid and transport users (e.g. services to the grid with smart charging). Further, the solar availability in the region, which is indicated for high performance of energy supply through photovoltaic panels, could be exploited for replacing the conventional energy used by current transport, with renewable solar energy.

Therefore, the main objective of the paper is to present a study of an optimal route scheduling in coordination with the design of a photovoltaic charging-station (external parking lot) for the charging of electric mini-buses.

2. Method
The methodology is adapted to the regional needs and is based on the European Union’s requirements on the promotion of energy efficiency towards “green” transport and mobility, and the EU Directive for Intelligent Transportation Systems (ITS). The first step of the method includes the study and design of the optimal route scheduling in the region under the newly imposed constraints. This dictates the configuration of the electric mini-buses, so that their electrical specifications serve as the basis for estimating the power needed to fully charge them. The next step is the study regarding the specifications of all the ancillary equipment needed to support the operation of a solar charging-station, i.e. PV panels, inverter, batteries and charging controller specifications. Finally, a cost analysis for the solar charging-station will be performed. The methodology is intended to be applied to the Prespa Municipality and the Florina Municipality in Greece as well as to the Bitola Municipality in the Former Yugoslav Republic of Macedonia.

2.1. Optimal route scheduling principles
The Intelligent Transportation System consists of the supply of real-time information, regarding the e-vehicles’ availability through the day, booking, payment, etc., to the e-vehicles’ users (tourists, disabled persons, students) through a sensors-data collector-server-client application as well as information on user needs and network state. Smart phone apps tailored to the specific types of users will be developed.

Depending on the trip objective, the e-vehicles will be subject to dynamic and adaptive routing, thus reducing travel time and enhancing reliability. Especially in cases of incidents, this will be supported by optimal adaptive routing [1] in the stochastic time-dependent network of the new service. The network-level impact from adaptive routing will be estimated from a user-equilibrium traffic assignment model [2], in which users make adaptive routing decisions based on online information. In particular, users’ choice sets of routing policies will include link travel times as random variables with time dependent distributions, and the equilibrium will be in terms of distribution of link travel times, flow and other quantities related to the trip [3].

2.2. Determination of the specifications of the e-vehicles
The indicative technical specifications regarding the battery of the electric mini-bus are presented in Table 1:

| Table 1. Electric bus battery technical specifications. |
|--------------------------------------------------------|
| Electric bus Battery |                            |
| **Type**          | Lithium                    |
| **Total Nominal Voltage** | 120V                        |
| **Maximum Battery Charging Current** | 50A                        |
The charging station will have a capacity of up to two electric buses, while being capable of charging one bus at a time. The consumption per bus is calculated as follows:

According to the specified technical characteristics of the electric bus (Table 1), the battery voltage of the electric bus is 120V DC and the battery capacity is 540Ah. Moreover, the battery charging rate is 9 hours for full charging, and the per-hour charging rate of the electric car is 50A. Therefore, according to the above specifications, in order to fully charge the battery of the electric bus, the installed power of the photovoltaic panels should be at least:

\[ P_{\text{bus}}(W_p) = V (V) \times I (A) = 120 (V) \times 50 (A) = 6000 W_p \]

**Thus, the total installed power of the charging station so as to be capable of providing a full charge for the electric bus should be:** \( P_{\text{bus}}(W_p) = 6000 W_p \)

### 2.3. Specifications of the photovoltaic charging-stations (external parking-lots)

The Inverter is selected on the basis of the power system requirements. Therefore, the Inverter’s power output should be at least 6000 \( W_p \), i.e. 8000 \( W_p \). Moreover, the Inverter’s AC current output should be greater than or equal to the AC current input of the electric bus. The latter is approximately equal to:

\[ I_{\text{AC input - bus}} (A) = \frac{P_{\text{bus}}(W_p)}{V_{\text{AC}} (V)} = \frac{6000 (W_p)}{230 (V)} \approx 26 (A) \]

Therefore, the Inverter’s AC current output should be greater than or equal to 26 A.

Finally, the Inverter’s rated DC input voltage should be 48V, and, thus the Inverter’s maximum DC input current should be:

\[ I_{\text{DC input - Inverter}} (A) = \frac{P_{\text{Inverter}}(W_p)}{V_{\text{DC}} (V)} = \frac{8000 (W_p)}{48 (V)} \approx 160 (A) \]

Summarizing, the Inverter's required specifications are presented in Table 2:

| Table 2. Inverter’s technical specifications. |
|---------------------------------------------|
| **Rated Power Output** | 8000W |
| **Output Voltage / Frequency** | 230VAC / 50Hz |
| **Minimum Current AC** | 26A |
The charging regulator is selected based on the power system requirements. Therefore, the charge controller’s power should be greater than 6000 Wp. Moreover, the charging controller’s output current should be less than the Inverter’s DC input current, i.e. less than 160A.

Regarding the battery side, the charging controller’s nominal battery voltage should be 48V. Finally, regarding the photovoltaic array side, the charging controller’s current input should accept low currents so that the cable dimensions are small as well. Therefore, indicative current values should be in the range 20A – 30A. In turn, the voltage input should be high enough so as to have a power of 6000W, i.e. the voltage input should be in the range 200V – 300V.

Summarizing, the charging controller’s required specifications are presented in Table 3.

**Table 3. Charge Controller’s technical specifications.**

| Specification               | Requirement       |
|-----------------------------|-------------------|
| Minimum Power               | 6000W             |
| Output Current              | < 160A            |
| Nominal Battery Voltage     | 48VDC             |
| Minimum Charging Power      | 6000W             |
| Input Current               | 20A – 30A         |
| Input Voltage               | 200V – 300V       |
| Protection                  |                   |
| From short-circuit          | √                 |
| From overloads              | √                 |
| From high temperatures      | √                 |
| From hypertension & hypotension | √             |
The required batteries’ capacity is determined by the capacity requirements of the electric bus, which, according to Table 1, is 540Ah. Therefore, the batteries’ total capacity should be greater than 540Ah. In order to achieve the required voltage and system capacity, the batteries should be connected as presented below:

Two (2) parallel arrays of twenty four (24) batteries of 2V, connected in series, with a total output voltage:
\[ V_{batout} (V) = 24 \times 2 = 48V \]
and capacity:
\[ I_{batout} (Ah) = 323Ah \times 2 \text{ arrays} = 646 \text{ Ah} \]
The batteries will be placed next to the charging station in an open-type concrete building (natural ventilation system through louvers).

The system’s total required power for the charging of the electric bus is 6000 Wp. Therefore, the following circuitry is performed:

- 27 photovoltaic panels with total power 6210W (27 panels x 230W = 6210W), which will be divided into 3 arrays of 9 panels each.
- Total output voltage per array is \( V_{out} (V) = V_{max} \times \text{panel number in the array} = 30V \times 9 = 270V \), and total output voltage is \( V_{out} (V) = 270V \) as well.
- Total output current per array is \( I_{out} (A) = I_{max} = 8A \), and total output current is \( I_{out} (A) = I_{max} \times \text{arrays’ number} = 8 \times 3 = 24A \).

An indicative view of the charging station is shown in Figure 1:

![Figure 1: View of the charging station.](image)
2.4. Cost analysis
In this section, an indicative cost of the charging station (parking) is presented, according to the previously specified/determined system requirements. More specifically, the indicative cost per system component, as well as the whole charging station’s (external parking-lot’s) indicative cost are presented in Table 4.

Table 4. Indicative component cost and whole station’s cost.

| Component                  | Cost  |
|----------------------------|-------|
| Photovoltaic Panels        | 4.500 € |
| Batteries                  | 4.500 € |
| Charging Regulator         | 800 €  |
| Inverter                   | 4.200 € |
| Cables and ancillary parts | 1000 € |
| Infrastructure costs       | 50.000 € |
| **Total Indicative cost**  | **65.000 €** |

3. Results
This study will significantly contribute to regional tourism development through the optimization of the road network for tourist attractions. Moreover, the study will provide efficient data regarding the design and cost of a solar charging-station (parking lot) for the charging of electric mini-buses. The mini-buses are intended to provide a student-transport and tourist-transport services within an intelligent transportation system in the regional route network.

The realization of the Intelligent Transportation System along with the development of a smart phone application, and the utility vehicles can facilitate people with special needs (elderly, disabled, distant-residents) in effectively realizing their daily on-demand transport and accessibility needs, particularly during the heavy winter periods. The scheduling and realization of the student transport by electric minibuses that are charged by RES will substantially reduce the cost of their transportation while increasing trip reliability for the new service. Service expandability and transferability will assure reduced costs in future applications, and will support capitalisation of the results across the region and in other locations.

All the outputs involve electric vehicles charged by RES, therefore contributing directly to the indicator CO34: Annual decrease of GHG. More specifically, the estimated annual decrease of GHG is 164,839 tons of CO2 equivalents/year. Moreover, the surface of improved cross-border road and infrastructure is estimated to be 1.000,00 square meters.

4. Conclusions
The realization of the above concept will result in the following:

(1) The provision of four electric minibuses and four utility cars that will transfer tourists and students at the routes that will be defined, as well as residents, especially elderly, disabled and distant-residents, on-demand.
(2) Four Renewable energy sources (RES)-supported external parking-lots will be designed and implemented.

(3) Through the utilization of smart phones, an intelligent Transportation, Client-Server application, will be deployed to the parking lots-e-minibuses.

(4) An optimal route scheduling for the transportation of tourists and students through a 20-year horizon, will facilitate solution of a yearly faced problem of the Municipalities. The reduced travel time is estimated to be 10 minutes, while the average border crossing travel time is estimated to be 30 minutes. Finally the energy efficiency awareness barometer is expected to reach the 80%.

References

[1] Gao, S. and Chabini, I. 2006 *Transportation Research Part B*, **40**(2):93–122.

[2] Gao, S. 2008, *TRISTAN*.

[3] Stephanedes, Y. J. and Yoldasis, C. 2016. *Schedule Update. PHAROS Integrated Eco-routing and Fleet Management System Project, ENPI/2014/343-446*. 