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Electric Vehicle Charging Stations in Macau

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Abstract

Electric vehicles (EVs) are clean due to their zero local emissions and low global emissions. They are also green due to their environmental friendliness, since electricity can be generated by renewable sources. Despite these obvious benefits, EVs have not been widely used around the world; the key reasons are due to their high initial cost, short driving range or lack of charging facilities. With the growing concerns on price fluctuation, depletion of petroleum resources and global warming, there is fast growing interest in EVs in Macau. Thus, it is a pressing need for researchers and power utilities to develop various infrastructures for EV. This paper aims to present a time delay method for EV charging station, by shifting the night-time battery charging within the off-peak period, results are to fill in the valley of the system demand curve**.**

Keywords: Charging stations, system demand leveling

1 Introduction

Battery powered electric vehicles (EVs) were one of the solutions proposed to tackle the energy crisis and global warming. However, the high initial cost, short driving range and long charging time have proved the limitation of battery powered EV [1-2]. The market of EVs remains in extremely limited extent by weight, lifetime and the constraint of cruising radius by one charge.

The daily energy consumption by an EV will be determined by the driving range/cycle and the charging time, while its impact on the electricity system demand will depend on the duration and pattern of charging. The electric utility‘s interest in EV lies in the anticipated and expected benefits beyond the simple increase in energy sales. It is expected that the EV charging load will be contained within system off-peak hours without affecting the peak demand, thus increasing the sale of low cost electricity. From the electric utility operation aspect, this potential to fill the valley [3] in the load curve will result in more electricity sales for the same system capacity [4].

As a solution of a new peak brought by quick charge on electric demand, a diesel generation is a policy of peak demand generator for the time being, but which becomes a very expensive investment as the facility of countermeasures only for few peak hours. In some countries, it was considered that the EV battery to be one of the energy source when it is not moved. So it is very attractive to extract electricity from the EV battery, especially for private use, that can be seen not to be used around noon. The implementation of such vehicle-to-grid (V2G) technology depends on the communications support, interfaces for communication between the grid, charging points and EVs [5].

In this paper, an EV charging station has been designed for both research and teaching purposes.

The EV charging load will be programmed and shifted to fill the valley of the system load curve without regard to localized effects [4].
The charging station was also proposed for management of an EV fleet of a local electric utility; with some modification to include a payment system for public use.

2 Information of Macau

Macau, also spelt as Macao, lies at the mouth of the Pearl River Delta of Guangdong Province, China, about 65km west of Hong Kong. The Territory consists of Macao peninsula, and two islands—Taipa and Coloane as shown in Fig. 1. Colonized by Portugal in the 16th century, the Portuguese and the Chinese have cultivated in the city a unique blend of the two cultures. On 20 December 1999, Macau was returned to China and is known as Macao Special Administrative Region (Macao SAR).
Information from the Statistics and Census Service [6] indicated that total land area of Macao measured 29.5 km^2 as at the end of 2009, with the total population of 556,800, with 95% of its population being Chinese, and the rest were Portuguese, Europeans and others.
With an urbanized city and limited land space, Macau has been faced with problems of road congestion and rapid growth in car population. Vehicle population was increased from 113 to 196 thousands from 1999 to 2010. From Table 1, the total number of motor vehicles is steadily increasing, with 196,634 licensed by the end of 2010. Total length of public roads in Macau was 413.1km, and the motor vehicle density was 476 vehicles per kilo-meter. However, the typical average daily driving range of vehicles is less than 40 km as shown in Table 2.

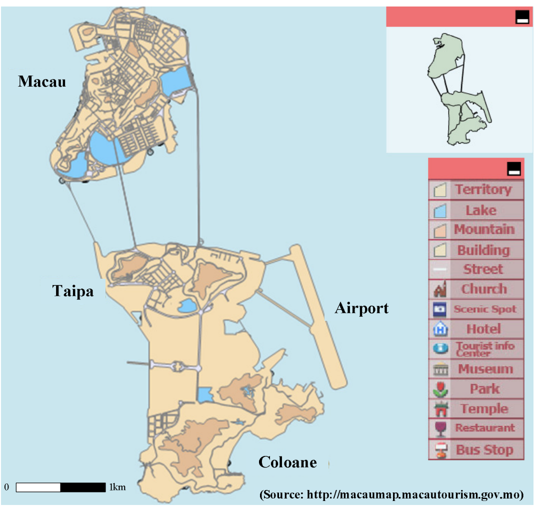

Figure 1: Map of Macau.

From Table 1, the total number of motorcycles is steadily increasing, with 106,420 licensed by the end of 2010, 54.1% of total number of vehicles in Macau.
With the growing concerns on price fluctuation and depletion of petroleum resources and global warming, there is fast growing interest in EVs in Macau. Air pollution is also another important concern. If this fossil-fuel trend continues from conventional cars, the sky will become permanently gray [7]. Thus, it is a pressing need for researchers and power utilities to develop various infrastructures for EV, while the electric utility's interest in EVs lies in the anticipated and expected benefits of increase in energy sales, and the EV charging loads will be contained within system off-peak hours without affecting the peak demand. A sizable EV load can introduce a new peak in the early off-peak period. It may have scheduling implications, and completely throw any load management programs off balance [4], if they are not properly programmed/shifted.
This paper focus on the development of charging facilities for the possible market of EVs in the Macau area [8], the proposed charging stations are particularly suitable for both business users and electric utility.

3 Design of EV Charging Stations for Macau

The impact of EV loads on the energy demand is determined not only by the number of EV in use and their usage pattern, but also by the number of EV being charged at any instant and the charging

Table 1: Number of Vehicles in Macau

Year	Total	Light Vehicles	Heavy Vehicles	Motor Cycles
2006	162,874	71,726 (44.1%)	5,780 (3.5%)	85,368 (52.4%)
2007	174,520	76,117 (43.6%)	6,107 (3.5%)	92,296 (52.9%)
2008	182,765	78,753 (43.1%)	6,288 (3.4%)	97,724 (53.5%)
2009	189,350	80,499 (42.5%)	6,285 (3.3%)	102,566 (54.2%)
2010	196,634	83,879 (42.7%)	6,363 (3.2%)	106,420 (54.1%)

Table 2: Typical Cruising Ranges

Private	8km
Business	20km
Special (e.g. Fast-food delivery)	40km

profile of the battery module. It would be logical to charge an EV only during the off-peak hours so as to fill up the valley in the system load curve; it may not always be feasible. The following factors were studied to facilitate the design of the charging station:

- The load curve of local electric utility;
- The electricity tariff structure;
- The travel model of vehicle users;
- The typical battery charging curves (electric motorcycles were chosen for this project).

3.1 Electricity Demand Curve and Tariff

A load diagram of a local electric utility is shown in Fig. 2, while the electricity tariff structure is tabulated in Table 3. From Fig.2, the system load decreases after 20:00 hours until 08:00 hours of the following day. The power company defined the off-peak period from 20:00 hours to 09:00 hours of next morning as shown in Table 3, according to the recorded load curve in Fig. 2.
From the utility's point of view, the EV battery charging should proceed within the off-peak hours, in order not to increase the system demand and the installed generation, transmission and distribution facilities are sufficient to cater for those additional charging loads. As a user, it would also be more economical to charge their

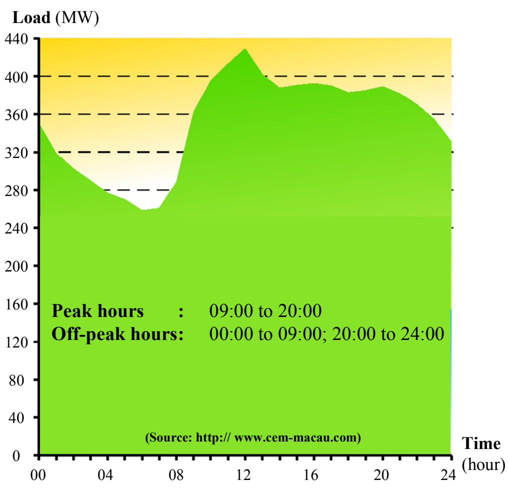

Figure 2: Typical daily load curve.

Table 3: Electricity Charge (MOP, 1USD≈8MOP)

Demand		21.484 per kW
Active Power	Peak hours	0.874 per kWh
	Off-peak hours	0.767 per kWh
Reactive Power	Peak hours	0.348 per kVARh
	Off-peak hours	0.116 per kVARh

EVs during the night-time with a comparatively lower power charges as depicted in Table 3.

3.2 Driving Pattern in Macau Area

Motorcycles are not only widely used by private users but also business users, more than half (54.1%) of licensed vehicles in Macau are motorcycles (106,420 recorded at the end of 2010). It is straightforward to broaden the EV market by first choosing electric motorcycles.
The travel patterns of different types of motorcycle user were schematically shown in Fig. 3, and night-charge periods were imposed on the same diagram when an EV is employed. In Fig. 3, charging would happen at any instant if not properly organized. Furthermore, V2G was not suitable for Macau since most private vehicle users would travel during lunch hours. The average cruising range in Macau area was also summarized in Table 2.
If no additional measures to manage the charging loads, the EV charging loads would create an additional burden to the generation, transmission and distribution facilities. The major purpose of this project is to delay the EV charging loads to after 20:00 hours and contain them within the off-peak period defined by the power company.

3.3 Electricity Demand by Night-charge

The characteristics of a typical electric motorcycle being studied were tabulated in Table 5, with a battery charging rate (temporal variation of the charging load per unit of recharging energy) shown in Fig. 4.
As shown in Table 5, the maximum range per one night-charge was 45km, which was greater than the average cruising range of most users in Macau, so one night-charge was sufficient to fully charge a motorcycle for all general users. According to the battery charging curve of the motorcycle being studied shown in Fig.4, the time for a full charge is about 6 hours.

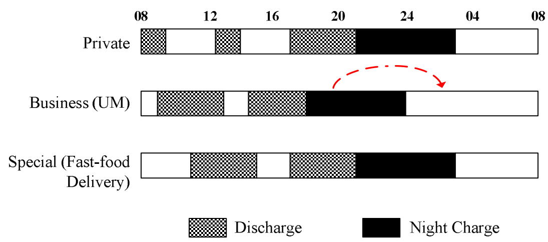

Figure 3: Travel model of different types of motorcycle.

Table 5: Properties of Electric Motorcycle

Vehicle type	Scooter
Motor type	Brushless a.c.
Rated power	0.6kW
Maximum power	1.2kW
Battery type	Lithium- ion
Battery voltage/capacity	25V/14Ah
Charging time	~4 hours (90%)/ ~6 hours (100%)
Range (Fully charged)	45km

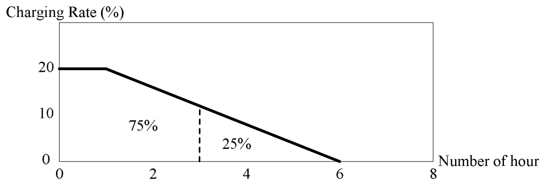

Figure 4: Battery charging characteristics (6-hour charge).

3.4 Shifting of Charging Loads

In Fig. 2, the off-peak period defined by the power utility was between 20:00 hours in the evening to 09:00 hours in the next morning, the total duration of off-peak period was 13 hours. From the measured charging current shown in Fig. 4, 75% of the battery would be charged within 3 hours. It is proposed to divide the EV loads into different groups, and the start-time between groups would be separated by 2 to 3 hours.

The anticipated charging currents were simulated with different combinations of group/separating hour. Results were shown in Fig. 5.

4 Design and Implementation of EV Charging Station in Macau

The charging station at University of Macau (UM) is primarily intended to demonstrate the practical implementation of theoretical approaches mentioned in previous section of this paper and to serve as a teaching tool for academic programs. The overall structure was shown in Fig. 6 to 8.

The charging station was a system for connecting EVs to the power grid for charging (refueling). The hardware and software concept covers user authentication, management, measurement and fleet administration.

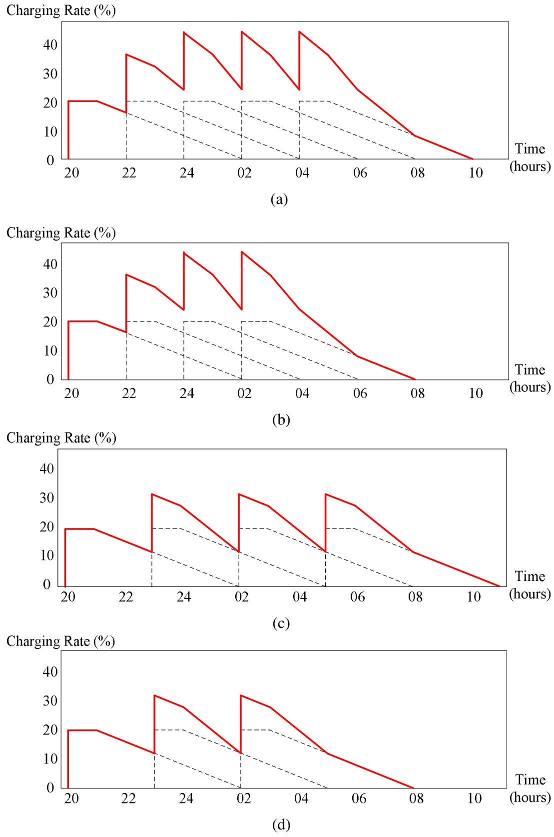

Figure 5: Simulated charging characteristics for different combination of groups/separating hours: (a) 5/2; (b) 4/2; (c) 4/3; and (d) 3/3

The whole system were implemented with an industrial PC, proximity card reader was used for validating and recording activities of both drivers and vehicles. When checking-out an EV, drivers were required to use their staff card for validation with PIN. Both staff card and vehicle card were required for checking-in an EV, car-park number and odometer readings were also required. Numeric keys on the touch-screen have been integrated as an input/output interface for drivers and facilitate intuitive operation of the charging station. An intelligent energy meter was installed to monitor the electric power consumption and other relevant electrical parameters such as power quality performances; the control features of the energy meter were also used for initiating delayed charging at pre-programmed time intervals.

The station was designed to fuel a fleet of 9 EVs for UM, with their charging start-time divided into 3 groups, with starting times at 20:00, 23:00 and 02:00 hours respectively, according to scenario (d) in Fig. 5. When more EVs were to be adopted, the charging loads in Fig. 5 (b) with 4 groups separated by 2 hours would still be absorbed by the demand curve without additional burden on the maximum demand.

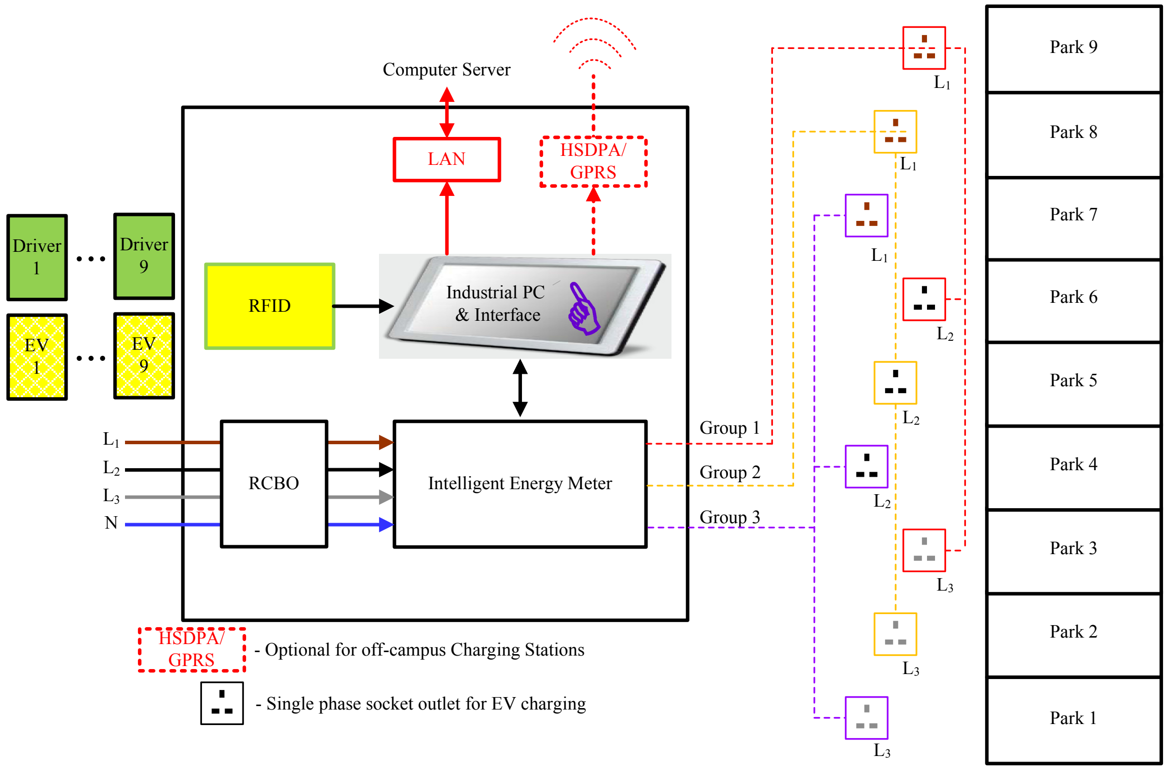

Figure 6: Schematic of the EV charging station.

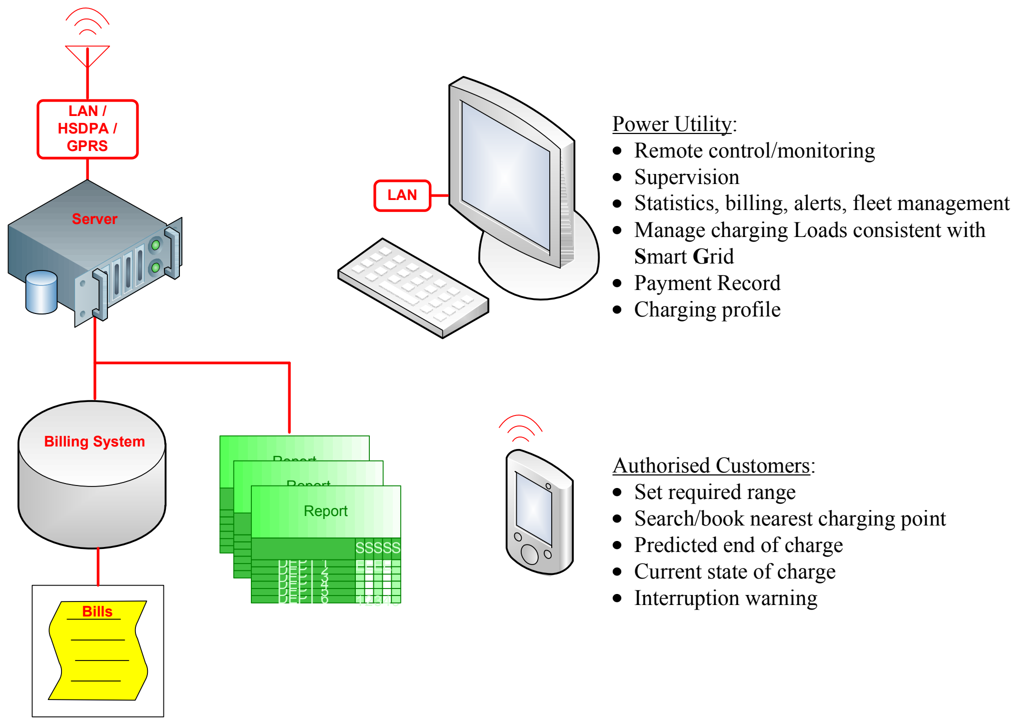

Figure 7: Schematic of the system server, control console and remote access by customers.

Since not all EVs were fully discharged when returned, the system was also designed to record the odometer readings and an intelligent energy meter was installed to record their respective charging profiles. Data collected would be utilized to determine the grouping combinations for delayed charging in the future. If the travel distance of any EV returned (e.g. during lunch break) was greater than the 70% of its maximum cruising range, the charging station was

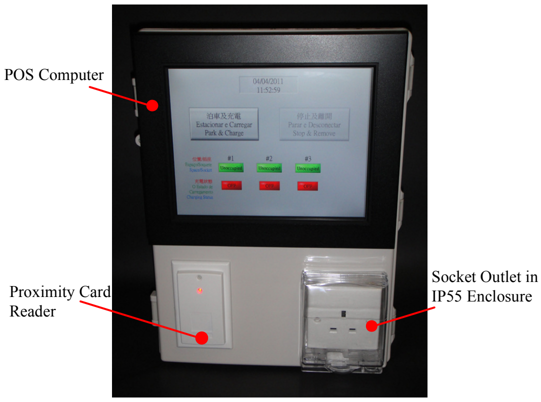

Figure 8: Experimental prototype.

programmed to start charging immediately. Proximity cards and reader were for administration and identification purposes, and would be implemented as payment system when the charging station was open for general public. Moreover, electrical safety, charging, measurement and protection systems were designed according to current standards [9] to [12]. A simplified prototype with only one socket outlet was built for experimental verification as shown in Fig. 8.

5 Conclusion

An EV charging station was designed and implemented for connecting EVs to the electric power grid for charging. The proposed system not only provided the fleet administration and load management features, but the system also shifted/delayed the EV battery charging period to the utility's defined off-peak period, conveniently filled the valley in the system load curve without regard to localized effects.

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