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Real-time Simulation Platform for The Coupling of Power System and Transportation Network

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ABSTRACT

Nowadays, large numbers of electric vehicles have been used all around the world. Moreover, in the near future, electric vehicles will continuously replace the petrol vehicles, and reduce carbon emissions in transportation systems. At the same time, considering a large numbers of electric vehicles (EVs) running on the real-world transportation systems, the temporal spatial electricity charging in real-time is an essential problem for the underlying power system. In this paper, we present a real-time simulation platform for the coupling of both the real-world transportation network and the power system. In this proposed platform, an open source traffic simulator called SUMO is adopted to simulate the electric vehicle charging in the real-world transportation network. And, a power system simulator implemented in Matlab is adopted to simulate the electric vehicle charging in the power system. The real-time communication interface is deployed to exchange message between transportation network and power system, which is implemented by a typical TCP/IP message protocol. The simulation results demonstrate that the proposed platform can real-time simulate the coupling of the real-world transportation network and power system and improve the efficiency of the simulation process.

Keywords: electric vehicles, real-time, transportation network, power system, SUMO

1. INTRODUCTION

Nowadays, large scale renewable generations are installed all around the world to reduce carbon dioxide emissions. The Europe union has planned to reduce carbon emissions to 80% by 2025 [1]. The European Wind Initiative plans to integrate wind energy to supply half of Europe's electricity for 2050 [2]. Renewable energies are encouraged to be deployed by Germany [3] and Australia [4]. In addition, the transportation sector contributes large percentage of carbon emissions. In 2017, 24% carbon emissions are produced from transportation sector [5]. In Europe, the carbon emissions of transportation sector are about a quarter of total emissions [6]. Thus, the electric vehicle has been put forward on the agenda to replace gasoline vehicles. However, when there are large numbers of EVs running within the real-world transportation systems, the temporal spatial electricity charging in real-time is an essential problem for the underlying power system.

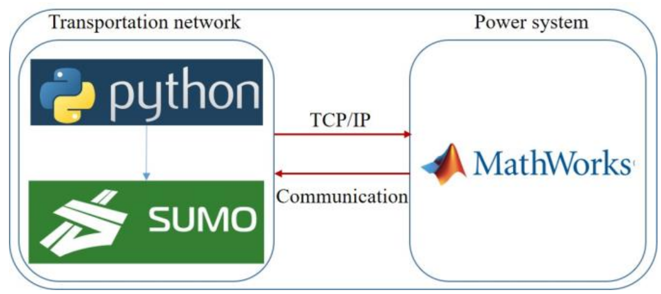

Fig. 1. Real-time simulation platform for the coupling of real-world transportation network and power system

Regarding the coupling of the transportation network and the power system, there are some existing works. In [7], authors study the coordinated dispatching of distribution networks and transportation networks. The EV charging demands are calculated based on the spatial traffic flows. In [8], authors consider a wireless electrified transportation network, and study the coordinated operation of the transportation system and power system. In [9], authors study the coordinated operation of the transportation network, natural gas,

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and active distribution networks. The charging demands are calculated based on traffic link flows. In [10], authors present a planning model for distribution system coupled with transportation networks. The charging demands link with the two systems. In [11], authors present the scheduling and trading of microgrids coupled with transportation networks. The fast-charging station links between the microgrids and the transportation network. The microgrid aims to minimize the operation cost via energy trading and electric vehicle charging.

However, in the above papers, the comprehensive real-world transportation network is not considered. The real-time simulation for the coupling of the comprehensive real-world transportation network and power system still lacks enough investigations.

In this paper, we present a real-time simulation platform for the coupling of the real-world transportation network and the power system. A open source traffic simulator, i.e., SUMO, is adopted to simulate the electric vehicle charging in the real-world transportation network. A Matlab-based power system simulator is adopted to simulate the electric vehicle charging in the power system. The real-time communication interface is deployed to exchange message between transportation network and power system, which is implemented by a typical TCP/IP message protocol. The structure of this simulation platform can be seen in Fig. 1.

The contributions are summerized as follows:

1. A real-time simulation platform for the coupling of real-world transportation network and power system is developed;
2. An IEEE 30 network is presented as the power system to supply electricity, and a real-world transportation network locates in Shenzhen, China is adopted to simulate charging demands.
3. A real-world transportation network is implemented to simulate the electric vehicle charging demands;

The remainder of this paper is organized as follows. Section 2 describes the coupling of the transportation network and power system. Section 3 presents the real-time simulation results. Finally, Section 4 concludes the paper.

2. COUPLING OF THE TRANSPORTATION NETWORK AND THE POWER SYSTEM

In this section, the coupling of the transportation network and the power system is presented, three parts are included, real-world transportation network, power system network, and a communication interface between these two networks.

2.1 Real-world transportation network simulator

A widely used traffic simulator SUMO is deployed to simulate the electric vehicles running on the real-world transportation network. The real-world network locates in E: 113.93; N: 22.57, Shenzhen, China is implemented, which is presented in Fig. 2.

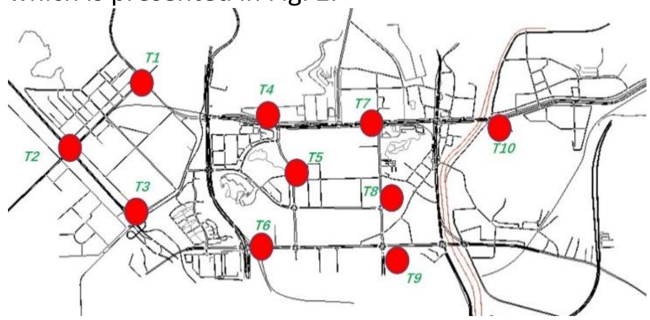

Fig. 2. A real-world network model

There are ten charging stations in the real-world transportation network. Electric vehicles are travelling around in the network and finding a charging station to charge electricity. Other existing charging strategies that out the scope of this paper would be explored in the future works.

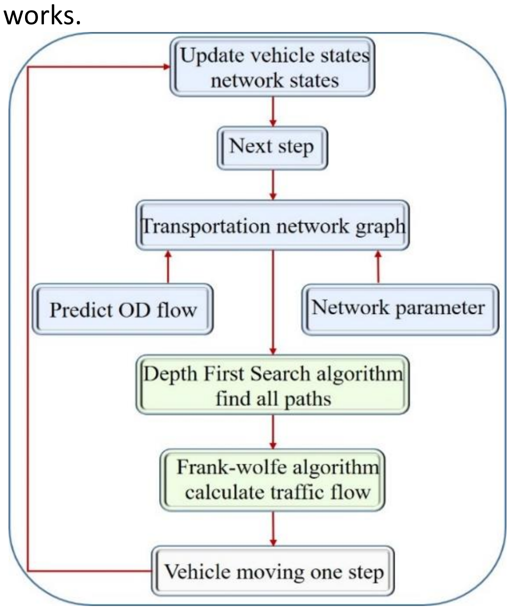

Fig. 3. Transportation network running

The traffic modelling via the SUMO simulator includes different parts, which is presented in Fig. 3. Firstly, the transportation network parameters, and the predicted origin-destination traffic demands are obtained. Second, based on the obtained parameters, the traffic flow assignment problem based on depth first search algorithm and the Frank-wolfe algorithm is solved. Third, based on the traffic flow assignment results, vehicles move forward for one simulation time step. Last, the vehicles position, states, and the transportation network states are updated, and the next step is executed. This simulation procedure is repeated until the last step is achieved.

The SUMO traffic simulator is controlled by the simulation script powered by the python language. The vehicle states, charging demands, and other parameters can also be controlled and visualized.

2.2 Power system network simulator

A Matlab based power system simulator is adopted. An IEEE 30 nodes network is adopted to provide electricity to charging stations, which is presented in Fig.4. Ten charging stations are interconnected into the power networks. Electric vehicles will charge at the stations.

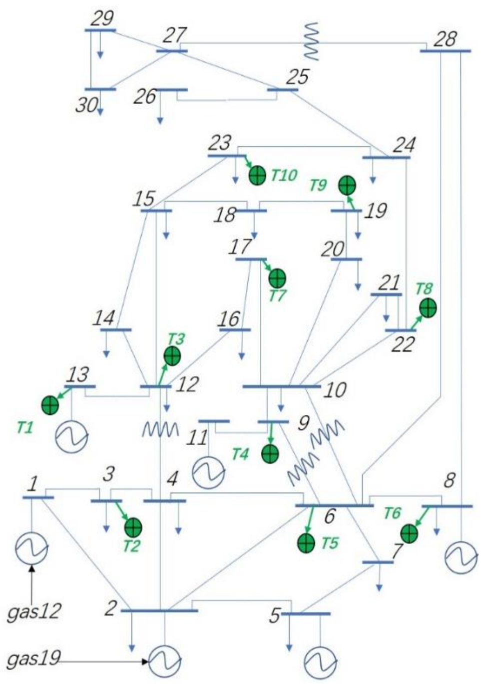

Fig. 4. An IEEE 30 nodes power network.

Power system operation is presented as the traditional optimal power flow problem, and is solved in the Matlab software, which can be represented as follows:

$$\min_{P_g,Q_g,V} C_{ug} = \sum_{i=1}^{n_g} \{f_P^i(P_g^i) + f_Q^i(Q_g^i)\}$$

$$P_i^g = P_i^{load} + \sum_{j=1}^{n_{bus}} V_i V_j (G_{ij}^{line} cos\theta_{ij} + B_{ij}^{line} sin\theta_{ij})$$

$$Q_i^g = Q_i^{load} + \sum_{j=1}^{n_{bus}} V_i V_j (G_{ij}^{line} sin\theta_{ij} - B_{ij}^{line} cos\theta_{ij})$$

$$V_m^{i,min} \le V_m^i \le V_m^{i,max}; i = 1,2,\dots,n_{bus}$$

$$P_g^{i,min} \le P_g^i \le P_g^{i,max}; i = 1,2,\dots,n_g$$

$$Q_g^{i,min} \le Q_g^i \le Q_g^{i,max}; i = 1,2,\dots,n_g$$

where the P_g^i, Q_g^i are the real and reactive power of the i^{th} generator. f_P^i, f_Q^i are the individual polynomial cost function of the i^{th} generator. P_i^{load} Q_i^{load} are the real and reactive load demand at bus i. G_{ij}^{line} B_{ij}^{line} are the parameters of the power lines from bus i to bus j. V_m^i $V_m^{i,min}$ $V_m^{i,max}$ are the voltage magnitude, minimum voltage magnitude and maximum voltage magnitude at bus i. $P_g^{i,min}$ $P_g^{i,max}$ $Q_g^{i,min}$ $Q_g^{i,max}$ are the minimum and maximum real and reactive power of i generator.

2.3 Coupling between the transportation network and power network

A real-time communication interface implemented by the TCP/IP message communication is developed to exchange message between the traffic simulator SUMO and the power simulator Matlab, which is presented in Fig. 5.

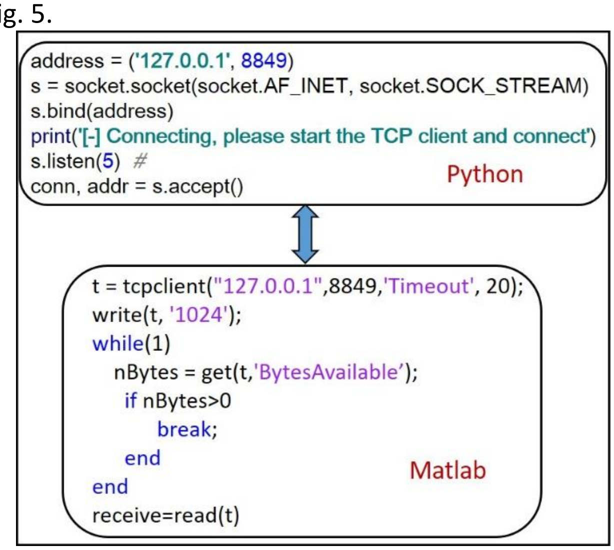

Fig. 5. A real-time communication interface, which is implemented by the TCP/IP communication protocol

3. REAL-TIME SIMULATION RESULTS

Based on the above coupling platform, we run the simulation, and the simulation process is presented in Fig. 6. Firstly, the TCP/IP client and server is started, and SUMO and Matlab are connected together. Then, through the TCP/IP commutation channel, transportation network electric vehicle charging data with Matlab are exchanged. At last, in Matlab, based on the charging demands from SUMO simulator, optimal power flow is solved, and the power network voltage is obtained. The charging power in ten stations are presented in Fig. 7. It can be seen that the temporal spatial charging demands based on the real-world transportation network are presented.

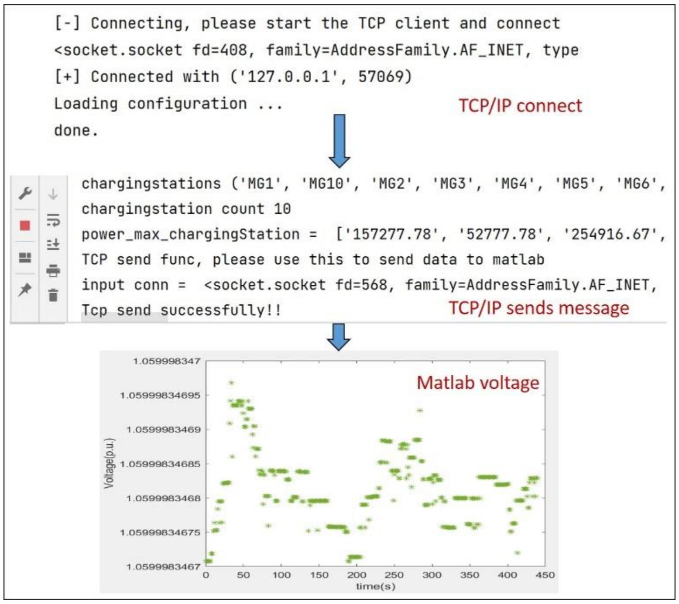

Fig. 6. The real-time coupling simulation process between SUMO and Matlab

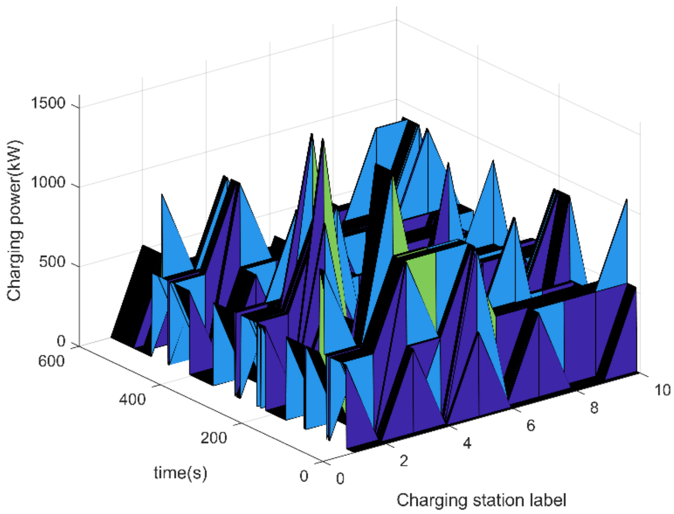

Fig. 7. Charing power in ten stations

4. CONCLUSIONS

In this paper, a real-time co-simulation platform for the coupling of the real-world transportation network and the power system is proposed. First, a SUMO open-source traffic simulator is adopted to simulate the electric vehicle charging in the real-world transportation network. Second, a Matlab power system simulator is adopted to simulate the electric vehicle charging in the power system. Third, the TCP/IP message handling is deployed to exchange message between SUMO and Matlab. The simulation results demonstrate that the proposed platform can real-time simulate the coupling of the real-world transportation network and the power system.

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