Smart management of energy consumption in urban transportation using Homer

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Abstract
Among the serious problems that the world is facing today, environmental pollution and lack of energy resources follow the increasing demand and use of energy by human societies. In the past few years, electric vehicles have attracted attention due to their ability to reduce emissions. However, the electric transportation industry, especially electric railway systems and electric car charging stations, are among the major consumers of energy for the distribution grid due to the coincidence of the peak load consumption of these systems with the peak electricity demand of the grid. The development of a smart management system for electric vehicle charging demand can be considered a basic solution in facing this challenge and to better adapt to the comprehensive use of electric vehicles. Significant return energy from train braking and solar energy sources can also be effective solutions to solve the above problem. It is possible to use energies such as the energy from the sun's radiation and the return energy of train brakes as sources of distributed generations, energy storages, and also manage electric vehicle charging stations to reduce the share of the grid. The distribution helped in supplying power to the electric transportation system. Therefore, to manage energy consumption and reduce the adverse effects of the electric transportation system on the distribution grid, the optimal energy consumption model of an electric transportation system consisting of electric railway system and electric vehicle charging stations along with energy storage and distributed generations, It has been presented and simulated in the Homer software environment and the results have been compared with the traditional system.

Keywords: Electric Transportation, Smart Energy Management, Distributed Generations, Regenerative Braking.

Introduction

The rapid growth of urbanization and the number of vehicles has led to an energy crisis and a sharp increase in air pollution in urban and densely populated areas. According to a report from the Environment and Climate Change Organization of Canada (2022), the highest amount of greenhouse gas emissions was related to the oil and gas and transportation sectors [1]. Therefore, electric transportation systems are considered a suitable alternative to reduce carbon dioxide and other greenhouse gases. The use of electric vehicles has advantages over conventional vehicles, including zero emissions, lower fuel costs, comfort and better driving experience, etc., which can contribute to environmental sustainability [2].

Since the use of electric transportation systems is getting more and more popular and the number of electric car owners is increasing, the creation of suitable transportation infrastructure for these vehicles is an essential factor for the comprehensive use of electric vehicles [3,4]. The development of the electric transportation industry has been able to introduce a new research area to achieve effective methods for finding suitable locations and planning for installing charging stations [5]. The availability of a suitable geographic distribution of electric vehicle charging stations can minimize the travel time and wait in the refueling queue [6].

However, since the improvement of the infrastructure of charging stations and the establishment of new stations is time-consuming and has a high cost, and also considering the significant power required by charging stations, which causes unfavorable peak demand, this Although the stations are useful, they put pressure on the distribution grid, and therefore the main concern is in responding to the demand for charging electric vehicles. Therefore, to better address the frequent charging needs of electric vehicles, the development and planning of smart charging plans can provide satisfaction to the users of these types of vehicles [7]. Electric transportation systems may be used by the general public for personal driving or in commercial fleets such as taxis, buses, and general public transportation. These systems need more time for full charging (0.5 to 10 hours) and therefore congestion may occur at charging stations while several cars are in line [8]. Therefore, researchers should implement customized charge management strategies considering electric vehicle applications. For personal electric cars, factors such as driving distance, charging capacity, charging status, charging cost, etc. can affect the efficient allocation of charging stations [9,10]. On the other hand, scheduling strategies for commercial electric vehicles should mainly focus on maximizing on-road service time and continuous driving cycles to avoid the reduction of service profit and daily net income [11].

The low growth rate of charging stations compared to electric vehicles must be resolved before establishing large-scale electric transportation systems. This is although large-scale electric transportation systems can lead to the overloading of the distribution grid and a decrease in quality [12]. To increase the acceptance of electric cars, buyers should be assured that their cars will not be fully discharged on the road, without any charging stations around them or standing in long queues for charging. As an alternative solution, researchers have proposed a new approach to transfer energy from one electric vehicle to another vehicle (V2V), which is also called peer-to-peer (P2P) charging. This is a practical method of refueling an electric vehicle, which is useful for both the electric grid and the owners of these vehicles [13]. This energy management strategy can be a promising solution to adapt the loads added to the distribution grid, especially during peak times [14].

Recently, the application of distributed generations in the transportation sector, which has been reviewed in [15] and [16], shows that the use of energy storage systems (ESS) can reduce the adverse effects of such charging stations.

Thanks to the development of power electronics engineering, a new concept has emerged in the field of the distributed generations called regenerative braking (RB). This technology is about regenerating electrical energy during the braking process of trains [17-19]. There are various methods for utilizing the energy of train braking. This energy recovered from braking is generally wasted as heat, while optimization can lead to a 3-30% reduction in energy consumption and an increase in efficiency. Also, to reduce energy costs and better stabilize the grid voltage, one of the proposed solutions is to use roadside energy storage systems (WESS), which can lead to a reduction in peak consumption [20,21]. The development of railway electrical power supply systems (ERPSS) is also a challenge that has always undergone changes over time with the advancement of technology, and costs can be reduced by choosing the right model from among different models and developing the power electronic system [22].

Of course, it should be noted that the adverse effects of electric vehicle charging stations on the electricity grid are far greater than those of the electric railway system, because the power consumption of these stations is directly supplied by the distribution grid, while the electric railway system It usually has its separate feeding station [23]. Therefore, the energy obtained from train braking can be used not only within the train system itself but some of it can be provided to electric vehicles.

By reviewing the literature, it was found that by considering photovoltaic panels (PV), regenerative braking, and energy storage as distributed generation sources in an integrated structure, a smart configuration can be proposed to improve the performance of the electric transportation system. Therefore, the goal is to propose a smart energy management system consisting of the electric railway system, electric car charging stations, energy storage, and distributed generations, which will result in the formation of an optimal model for energy consumption, reducing infrastructure costs, and adverse effects of the electric transportation system on the distribution grid should also be reduced.

Electric Transportation System

The structure of the electric transportation system considered here consists of the electric railway system, electric car charging stations, energy storage, and photovoltaic panels.

The amount of electricity consumption in the electric railway system is variable, and in the meantime, losses due to train braking constitute a significant share of the total energy consumption of this system, and therefore, researchers are looking for solutions to improve the energy consumption model of such a system. Losses caused by train braking are on average half of the total energy consumed by the system [24], while it is possible to recover more than 30% of energy. This recovered energy can be used for the consumption of the system itself or even the excess energy can be transferred to the electricity grid or other trains [25]. Therefore, using the return energy of the train braking is a suitable solution to prevent the waste of large amounts of energy in the electric railway system.

With the proper placement of electric vehicle charging stations, it is possible to improve their accessibility and, as a result, increase public acceptance of electric vehicles. But on the other hand, these charging stations can have adverse effects on the distribution network due to their high power consumption. According to a report published by Virta. global in July 2021, in most countries, the average electricity consumption of an electric car is approximately 0.2 kWh per kilometer [26]. The power demand by electric vehicles overlaps with the peak consumption of the electricity grid and will lead to problems such as an increase in the peak consumption of the distribution grid, a decrease in reliability, voltage deviation, an increase in losses, and an increase in the cost of electricity consumption [27]. Therefore, the coordination between the capacity of electric vehicle charging stations and the distribution grid should be organized [28].

The energy storage in the electric transportation system model is used to reduce the peak power demand from the distribution grid and as an auxiliary power source to supply the energy needed by the system when necessary.

The electric energy produced by photovoltaic panels can also be used in the electric transportation system. These distributed generation sources can be used as auxiliary energy sources in electric railway systems and electric car charging stations and reduce energy consumption from the electricity grid and the resulting cost [29,30].

In the smart energy management system presented here, the electric railway system, electric vehicle charging stations, energy storage, and photovoltaic panels interact with each other to reduce the load imposed on the distribution grid by the electric transportation system. The proper arrangement of placing these components next to each other is determined depending on the system requirements and operating conditions. A suitable arrangement is that by choosing a DC bus as the mediator of energy exchanges, according to Figure (1), the components of the system are connected. In this structure, distributed generations and energy storage are directly connected to the DC bus, which, although it requires an advanced control system to stabilize and prevent bus voltage fluctuations, is more economical than other possible arrangements.

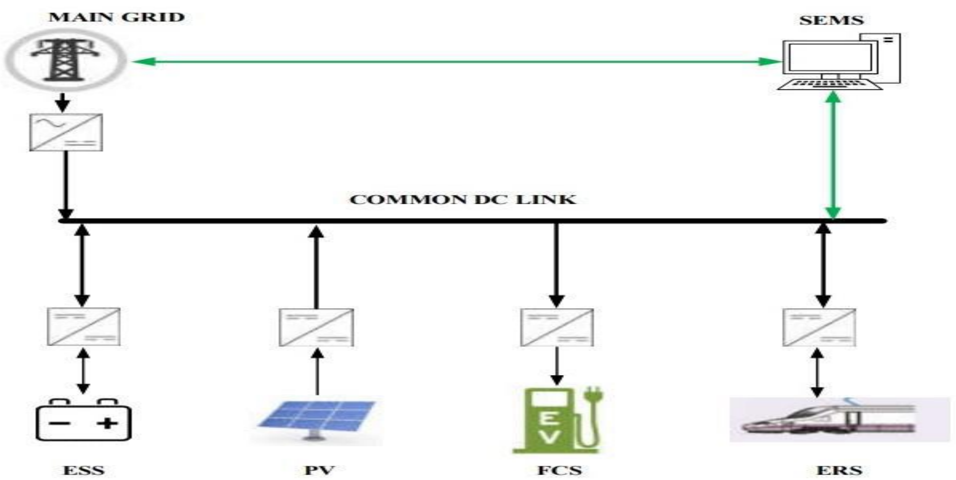

Figure (1) The proposed structure of the smart electric transportation system

Research Method

Optimization of power distribution

According to the introduction of the components of the electric transportation system in the previous part, the energy exchange between the components takes place according to (1).

$$P_{Grid} + P_{ESS} + P_{PV} + P_{Regenerative\ Braking} = P_{Charging\ station} + P_{Electric\ Railway} \quad (1)$$

On the left side of the equation, the power supply sources of the electric transportation system, i.e. distribution network (P_{Grid}), energy storage system (P_{ESS}), photovoltaic panels (P_{PV}), and regenerative energy from train braking ($P_{Regenerative\ Braking}$), are located. On the right side, the power consumers of the electric transportation system, i.e. electric car charging stations ($P_{Charging\ Station}$) and electric railway system($P_{Electric\ Railway}$) are located. The goal is to optimize the power drawn from the distribution grid (P_{Grid}) by considering certain values for other parameters of this equation.

Simulation with HOMER

In this part, the intended electric transportation system has been simulated in the HOMER software environment to obtain the optimal energy consumption model and determine the contribution of each distributed generation source and the distribution grid in providing the power consumption of this system in the most optimal state.

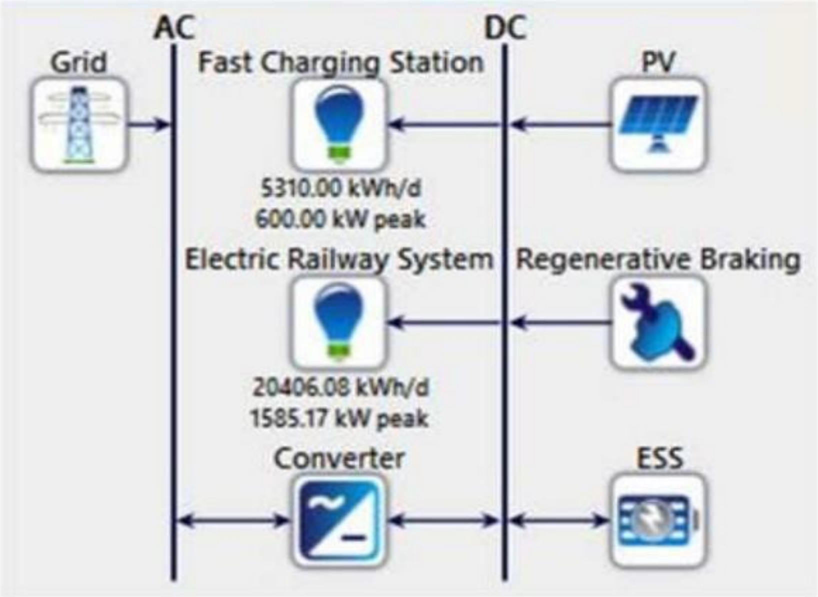

Figure (2) Configuration of the proposed system in HOMER

The load profile of the subway network and electric vehicle charging stations as software inputs, the value must be known. The load profile of the electric railway system every hour of the day is considered according to figures (3) and (4).

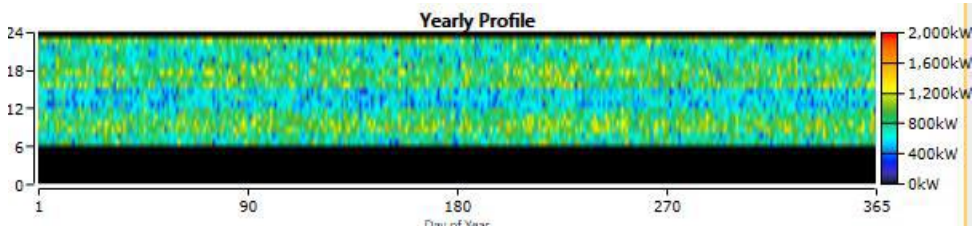

Figure (3) Electric railway system annual load

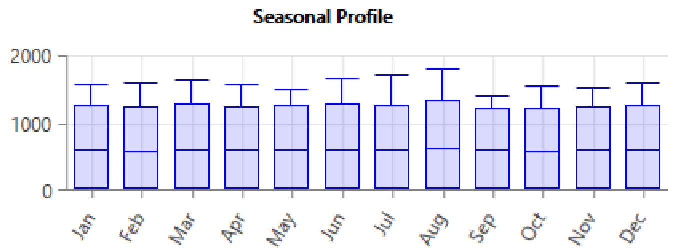

Figure (4) Seasonal graph of electric railway system load consumption

For the electric car charging station, by considering four 150 kW chargers [31], the load consumption profile is obtained according to figures (5) and (6).

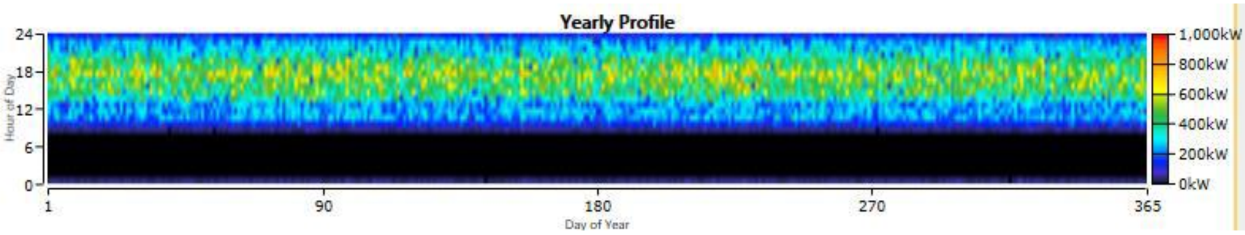

Figure (5) Load profile of electric vehicle charging station

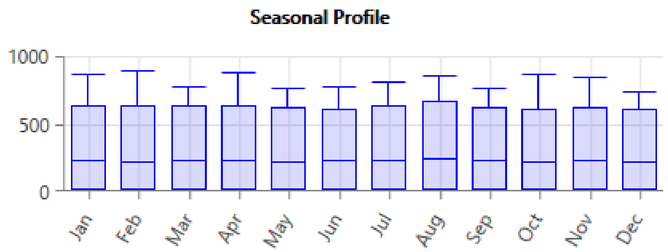

Figure (6) Seasonal chart of electric vehicle charging station

The total energy consumed by the electric transportation system during the day can be calculated from the total load profiles of electric railway system and electric car charging station.

In the next step, it is necessary to specify the solar radiation information related to the city of Tehran as another input of the software, so that finally the power profile produced by the photovoltaic panels in the proposed system can be determined. This work is done using the HOMER software which is connected to the NASA website and is according to figures (7) and (8).

Month	Clearness Index	Daily Radiation (kWh/m²/day)
January	0.550	2.730
February	0.574	3.620
March	0.553	4.500
April	0.556	5.510
May	0.576	6.390
June	0.636	7.350
July	0.623	7.040
August	0.636	6.560
September	0.647	5.640
October	0.593	4.050
November	0.560	2.940
December	0.523	2.380

Figure (7) Sunlight information

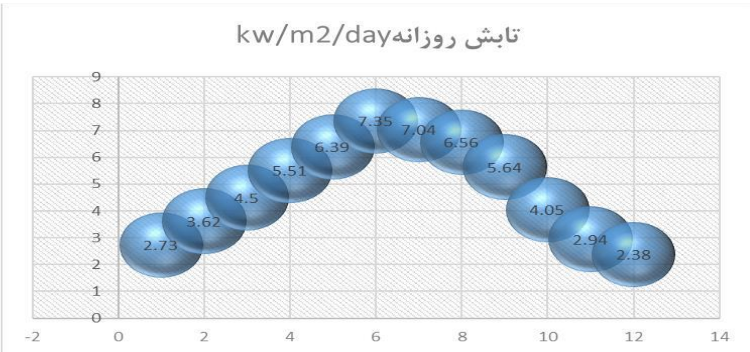

Figure (8) Daily radiation diagram of Tehran city

According to the initial explanations of the report, the return energy from train braking can be considered 30% of the total power consumption of the electric railway system. In this way, all software inputs are specified.
In the following, the simulation of the structure of the proposed electric transportation system has been done in the HOMER software environment. The schematic of the intended system is shown in Figure (2).

Results Discussion
From the simulation of the proposed electric transportation system model in the HOMER software, the values of each of the distributed generation and the power drawn from the electricity grid are obtained as simulation results in the output of the software. The difference between the proposed system and the traditional system in which consumers (electric railway system network and electric car charging stations) are fed by the distribution grid can be observed and analyzed.
Regarding distributed generation of photovoltaic panels, the profile of solar power production throughout the year in the proposed system is presented in the form of a diagram in Figure (9).

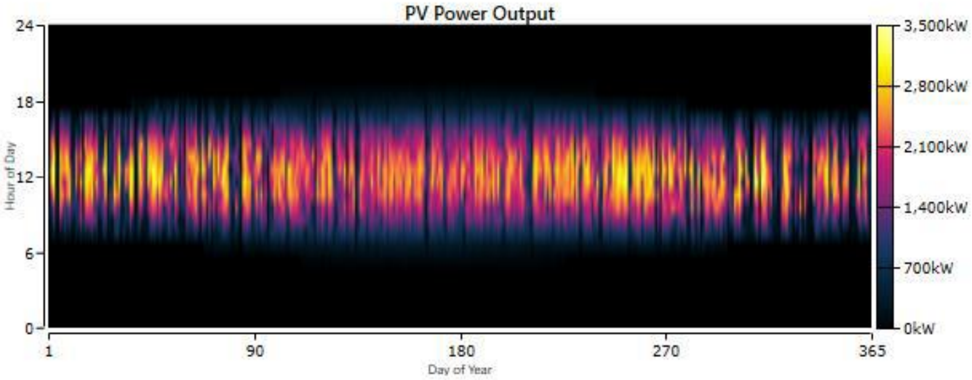

Figure (9) Output power of photovoltaic panels in 24 hours a day and 365 days a year

As can be seen in Figure (10), by using the smart energy management system, the peak consumption of loads is reduced from the monthly average of 2927 kilowatts to 1100 kilowatts per month due to supplying part of the consumption power of the proposed electric transportation system by distributed generations.

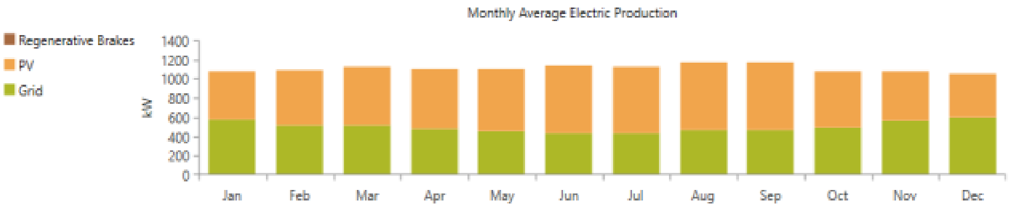

Figure (10) Average monthly electric power consumption in the proposed system

Also, the results show that the electricity purchased from the grid will decrease from 9775099 kilowatt hours to 4341816-kilowatt hours per year.
It is necessary to mention one point here. In the diagram of Figure (10), it can be seen that the energy recovered from the train braking does not contribute to the power supply of the electric transportation system, and the only distributed generation source that supplies a significant part of the system's energy consumption is the production power of photovoltaic panels. The reason is that even though using this generation of train braking has advantages, considering heavy costs of setting it up, using this source of distributed energy generation is not economical. Therefore, it is more economical and optimal to use only photovoltaic panels as auxiliary energy sources to reduce the grid load caused by the electric transportation system.
By comparing figures (11) and (12), it is possible to see the reduction of the adverse effects of the electric transportation system on the distribution network by using a smart energy management system. In the traditional system, all 9775099 kilowatts of power consumption of the electric transportation system are provided entirely by the electricity grid. But in the proposed system, the reduction of consumption from the grid can be seen during peak hours. Figure (13) also shows the excess energy sold to the grid in the proposed system.

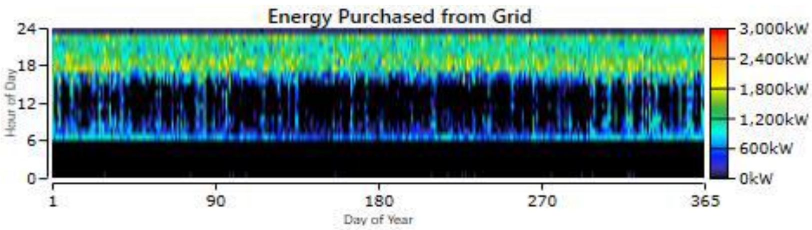

Figure (11) Power received from the network during the day and year in proposed system

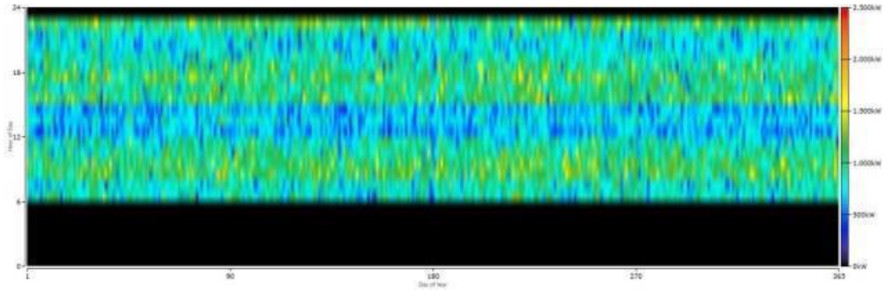

Figure (12) The power received from the network during the day and year in traditional system

Figure (13) Energy sold to the grid during the day and year in proposed system

Conclusions

The survey showed that in the past few years, the electric transportation system in many countries has been considered to reduce carbon emissions and improve air quality, as well as manage existing energy resources. However, it has raised the main challenge related to the imbalance between demand and production, especially during peak hours. Addressing the issue of how to efficiently manage demand and energy consumption by the electric transportation system can significantly remove the pressure of electricity demand from the distribution grid.

For this purpose, with a systemic view of the electric transportation industry, the proper arrangement of the electric transportation system including the electric railway system and electric vehicle charging stations along with distributed generation sources such as photovoltaic panels and energy recovered from train braking to reduce the load on the grid was presented and simulated in the HOMER software environment. The simulation results give the optimal system energy consumption model and show that the use of distributed generation along with the grid to provide a part of the power consumption of the electric transportation system, can reduce the adverse effects of this system on the electricity grid.

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