An Interoperability Platform for Electric Vehicle Charging Service Considering Dual System Operator and Electric Vehicle Owner Sides

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***Abstract*—The role of transportation in the overall emissions in light of the increasing environmental awareness has led to a rapid transition to the use of electric vehicles (EVs), especially in the last decade. The EVs have seminal advantages in terms of different point of views; however, they may pose vital challenges for the electric power system operation due to their stochastic characteristics as an electrical load. Several industrial and academic research studies have already been and are still conducted in this respect. Specifically, the development of combined technical and business-oriented operational models is extremely significant for sustainable penetration of EVs. In this study, an interoperability platform is proposed for EV charging service taking dual sides of the mentioned service as system operator and EV owner into account, being proposed as a new perspective in this area, also compared to industrial software platforms for EV charging service by service providers rather than power system operators. The developed software platforms are demonstrated and case study based analyses are conducted to present the applicability of the proposed concept.**

***Index Terms*—electric vehicles, interoperability, mobile application, system operator interface**

I. Introduction

A. Motivation and Background

The power system operators have recently been facing with a growing level of challenges especially with the increase of the peak demand, integration of higher amounts of variable renewable generation units, etc. while coping with the challenge of effectively managing the demand and supply balance.

The recently increasing penetration of new electric load types such as electric vehicles (EVs) may further boost this challenge vitally. The EVs have become a topic of wider interest in this manner especially with the increasing environmental awareness against the negative outcomes of the transportation sector responsible for a considerable ratio in global fossil fuel consumption [1,2].

Even the EVs have several pros for providing a sustainable replacement of conventional transportation concept, there are also major obstacles to be overcome before an EV dominated world becomes a reality. The problems directly related to the EV itself such as battery aging, limited ranges, comparatively longer refueling times, limited service possibilities are significant to solve in this regard [3,4]. However, one of the greatest drawbacks that the EVs may pose can be from the electric power system operator point of view. The possible uncoordinated integration of mobile EV load is very likely to have vital adverse effects on the power system assets and will be increasing the complexity of sustaining the demand and supply balance [5,6]. The coordination in EV charging service management is not a solely technical task. The business models considering technical points of the operation should also be improved in terms of a sustainable EV ecosystem development in the power system structure.

B. Literature Review

There are numerous studies realized for the analyses of impacts of the EVs on the power system operation and several concepts were proposed to tackle with these possibly arising operational problems in different literature examples.

Some studies considered solely the impact analysis of EV integration on the power system [7,8], while many others considered this complex operational problem to provide a coordinated EV charging management [9-13]. There are also different studies enhancing the details of the coordinated EV charging concept to an improved service level [14,15]. Different review studies on such EV integration subtopic can be found in Refs. [16-18].

Even there are many more studies that cannot be referred all here in such a short space for a comprehensive literature survey, a very few of them considered different aspects of the problem such as sociological, technical and economic points simultaneously in an interoperability platform dedicated to EV service management for charging purposes.

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C. Contributions and Paper Organization

In this study, an interoperability platform structure is proposed for an EV charging service ecosystem considering simultaneously the different stakeholders such as the system operator, EV owner, etc. Different software structures are developed and explained in detail technically. The structure outcomes are demonstrated via case studies including the technical intervention of the system operator to combine both technical (system operator point of view) and sociological (EV owner service satisfaction) aspects. The main contributions of this study can be emphasized as follows:

- A new platform that enables an interoperable operation of EV charging service is proposed to satisfy the requirements all the stakeholders of the problem in which the role of the distribution system operator is considered that differentiates this concept even from commercial similar structures.
- A mobile application is developed for EV owners enabling to convey the charging requests and receiving feedbacks including charging point reservation and navigation based supervision.
- An interface is prepared to more clearly demonstrate the charging service details as well as the decision making process outcomes to the system operator.

The rest of the paper is organized as follows. The overview of the proposed concept is detailed in Section II. Afterwards, Section III clarifies the case studies regarding the implementation of the proposed concept. Finally, Section IV highlights the important conclusions of the study.

II. Overview of the Proposed Concept

The proposed concept provides an interoperability platform where the charging stations, the system operator and the EV owners are combined in a single operational structure. The EV owners can convey their demand for charging to the common platform. The system operator can observe the detailed information about the power demand and occupancy of charging stations, as well as EVs charge state, then can set power limit for stations or even interrupt the charging process due to grid status. For the purpose of better explaining the concept of the adopted structure, the relevant general scheme is illustrated in Fig. 1.

As shown in Fig. 1, bi-directional data flow exists between all the participants of the system including the system operator, EV owner, and even an EV charging station aggregator if applicable. The charging stations convey the data including the number of EVs in the station, the information of occupant EVs and their charge levels, and the power drawn from the station in real-time to the system operator. The system operator, on the other hand checks dynamically the power grid status combined with the status of other loads, contingencies, overloading conditions for system assets, etc. When an EV owner delivers the charging request via the mobile application, the EV is directed to the most convenient station considering the data gathered from the charging stations and the power grid. The direction process ends when the EV reaches to the relevant station and starts to be charged. The general algorithmic scheme of the proposed interoperability platform is depicted in Fig. 2. The overall model consists of four subparts. The first subpart is the mobile application of the EV owner. The mentioned mobile application is developed in Xamarin.Net environment. Besides, the interfaces for the mobile application are presented in Fig. 3. Firstly, the EV owner should be affiliated with the mentioned interoperability ecosystem in order to have permission for using the mobile application. After being a member of the ecosystem, the EV owner then can convey the charging request by logging in the system with the personal information. The EV owner can observe all the available charging stations in the ecosystem, and can monitor his/her charging transactions history and EV technical specifications within the mobile application.

When the EV owner sends a charging request, the location and ID of the vehicle are automatically transmitted to the platform. The EV navigation application as the second subpart of the model receives the technical specifications of the EV with the relevant ID, and also the latest status of the charging stations from the cloud when a charging request is received. After this state, the application determines the distance of the EV from its current location to all the charging stations by the aid of Google Maps API, and also calculates the range the vehicle can reach with its current energy state and the relevant EV technical specifications as depicted in detail in Fig. 4. After this initial calculation, the socket status of the charging stations within the range of the EV is analyzed, and accordingly the proper stations are sorted considering their distances to the relevant EV. It should here be noted that the complex decision making process behind this subpart is not considered in the content of this study as this paper mainly focuses on developing the relevant platforms for the dual sides of the problem.

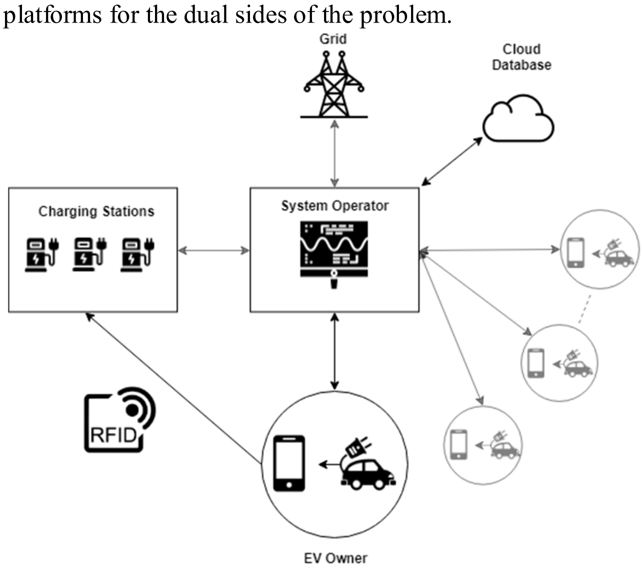

Fig. 1. General scheme of the proposed concept.

Herein, the traffic status between the EV and each station can also be a part of this evaluation and sorting process. When the EV owner confirms to be charged in the station suggested by the system, a navigation page is opened via the mobile application and the EV owner is guided to the relevant station.

The information regarding the station where the EV will be charged is conveyed to the cloud database through this subpart when the suggested station is approved by the EV owner.

The cloud database as another subpart of the model is realized in Microsoft Azure environment. The technical specifications of all ecosystem member EVs and EV owners, technical specifications of the stations, and logs of each charging event are stored in the mentioned database. Lastly, the fourth subpart of the model, namely the system operator interface, is designed in C# environment. The system operator interface consists of two subtabs as shown in Fig. 5.

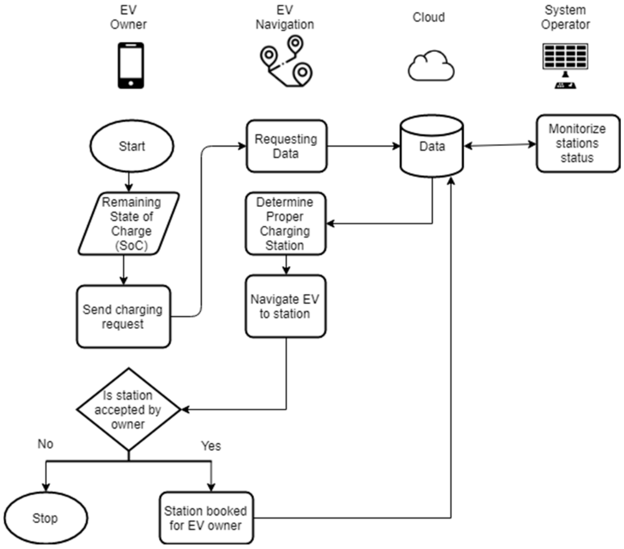

Fig. 2. General flowchart of proposed model.

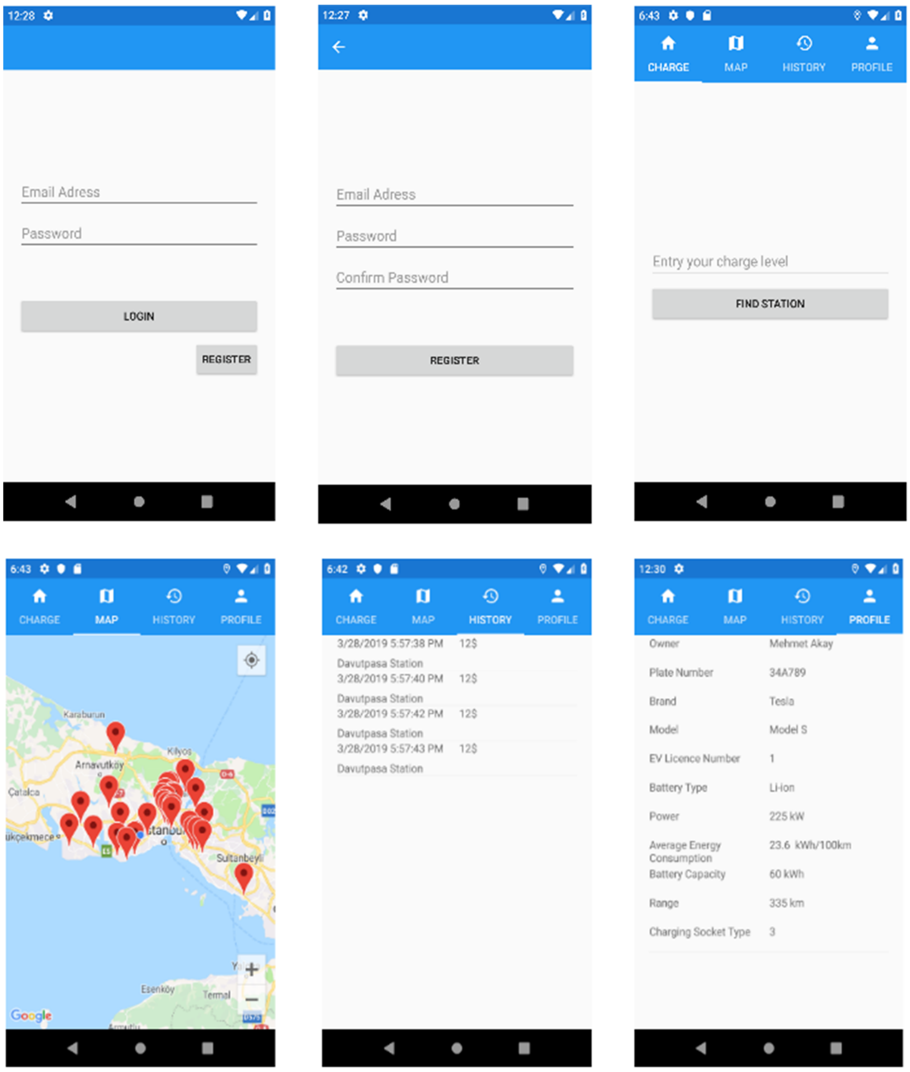

Fig. 3. EV owner mobile application interfaces.

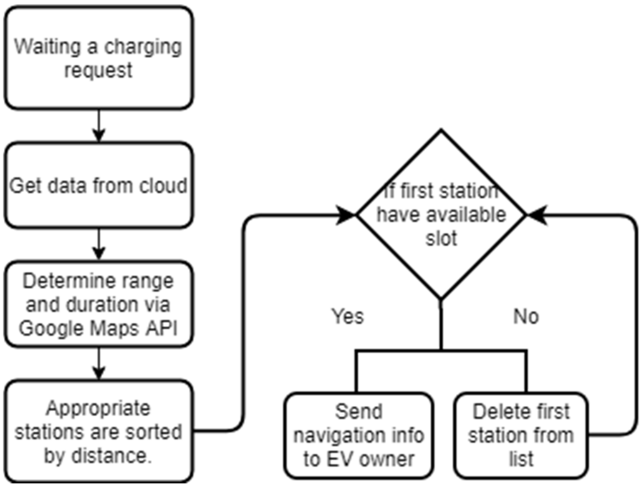

Fig. 4. EV navigation flowchart.

In the main page as the first tab, the system operator can observe all the charging stations within the ecosystem on a map. The stations with a high amount of available ports are marked in green, the stations with many reserved ports are marked in yellow, and the stations with many occupied parts are marked in red on the map. Accordingly, the system operator can easily analyze the regions with high charging demand density. On the other hand, the other tab named as the stations enables the system operator to analyze specifically each station in detail. In this tab, the system operator can observe the existing vehicle amount in each station, the station technical specifications, daily load variation, etc. Therefore, the system operator can lower the power of a station when the mentioned station starts to challenge the power grid with the extra load, or even can interrupt the charging process of vehicles as a last resort if necessary.

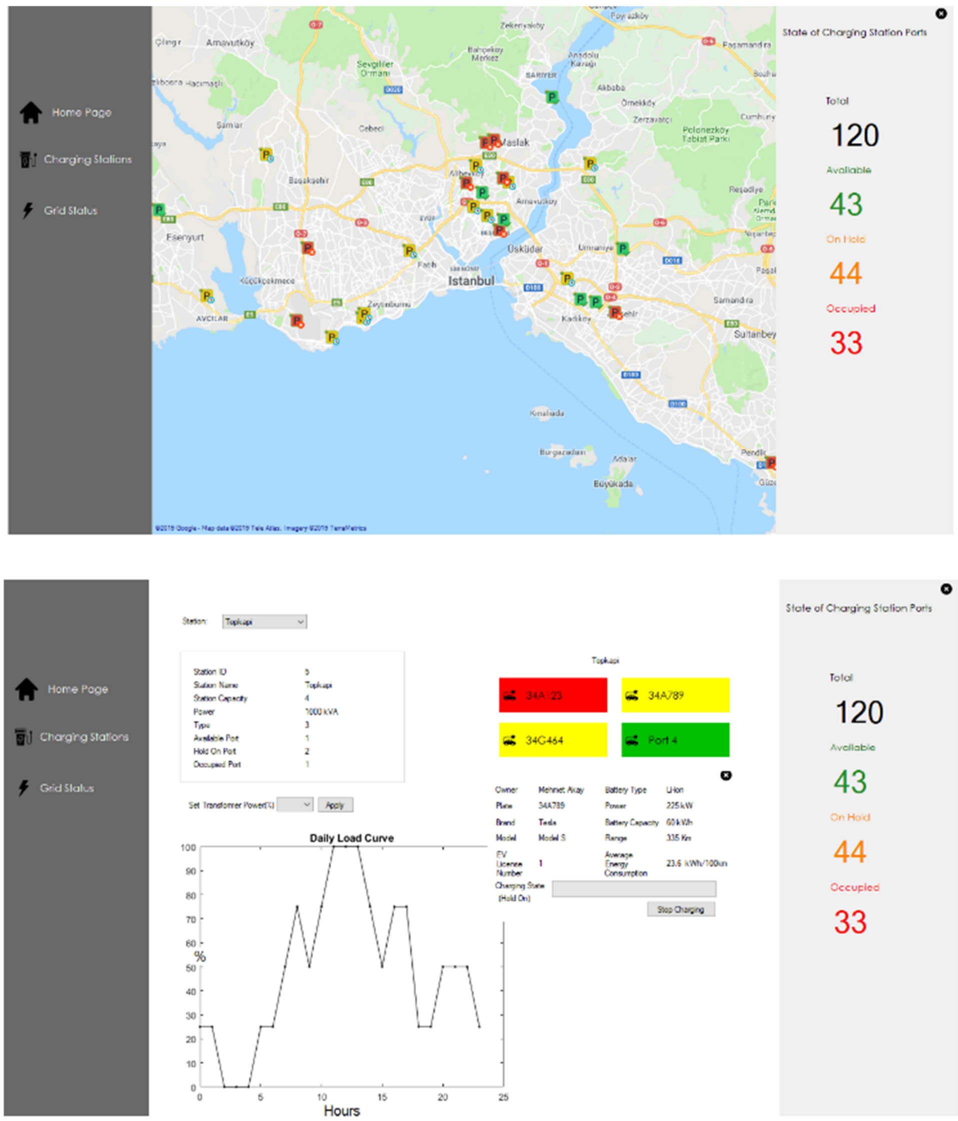

Fig. 5. System operator interfaces.

III. CASE STUDY

In the case study, 30 stations are located in Istanbul, Turkey as an example. In the imposed scenarios, it is assumed that each charging station has four ports for the charging service. The same EV sends a charging request to the platform via the mobile application with 10% state-of-charge in both scenarios as shown in Fig. 6 and the location during this charging request is assumed to be Yildiz Technical University Davutpasa Campus.

In the first scenario, the system operator does not impose any extra power grid based limitation, and therefore all the charging stations are available for the charging process. The three stations within the range of the EV with suitable port status and type are sorted as Topkapi, Bakirkoy1 and Atakoy stations from the distance point of view. When this scenario is tested, the EV is directed to Topkapi station as the nearest station. When the EV owner approves this station suggestion, one of the available ports of the relevant station is reserved for the EV. The EV owner mobile application and system operator interfaces for the mentioned direction process are demonstrated in Fig. 7.

In the second scenario, the aforementioned Topkapi station is prevented by the system operator due to a power grid condition. When this scenario is tested, it is observed that the platform directs the EV to Bakirkoy1 station as the second nearest station. The EV owner mobile application, and the system operator station limitation and charging status observation interfaces are depicted in Fig. 8. It is obvious that the platform also considers this time the power grid preservation oriented limitations of the system operator and chooses the convenient option by effectively considering dual sides of the decision making process.

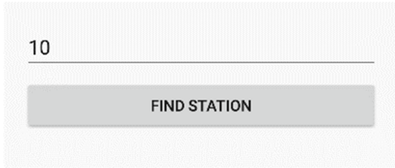

Fig. 6. The screen where the EV owner sends a charging request.

IV. CONCLUDING REMARKS

There have been vital developments in the world about the penetration of EVs with the support of developed and developing country governments and industrial stakeholders in the vehicle manufacturing area. On the other hand, much research has been (and still is) conducted about the impact of EVs as a load to the electric power system operation from several points of view. In particular, technical oriented business models are likely to have a vital role to boost the EV penetration while keeping the electric power system related drawbacks at acceptable levels.

In this study, an interoperability platform consisting of the system operator and EV owner, and even EV charging service aggregator sides was proposed. The relevant software structures for each stakeholder in this ecosystem were explained in detail with relevant technical specifications. Afterwards, the conceptually developed structure was tested via sample case studies where the developed interoperability platform performed effectively even in system operator intervention condition.

The future extension of this study will be on enhancing the system operator decision making process via implementation of a power flow based optimization problem formulation and also inserting the possible EV charging service aggregator into the action planning and operation.

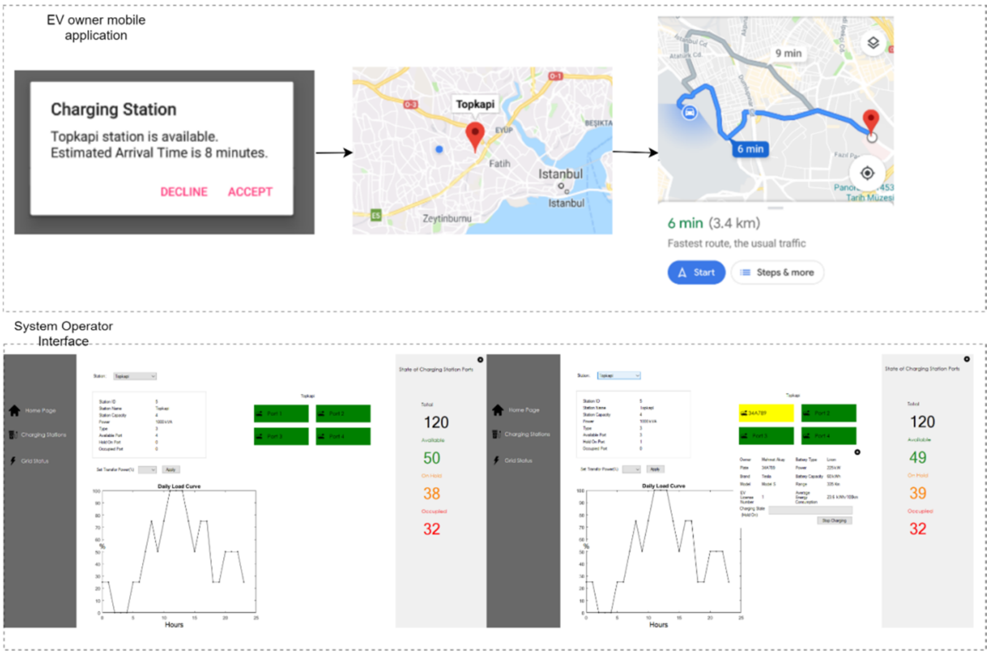

Fig. 7. The demonstration of the results for the first case.

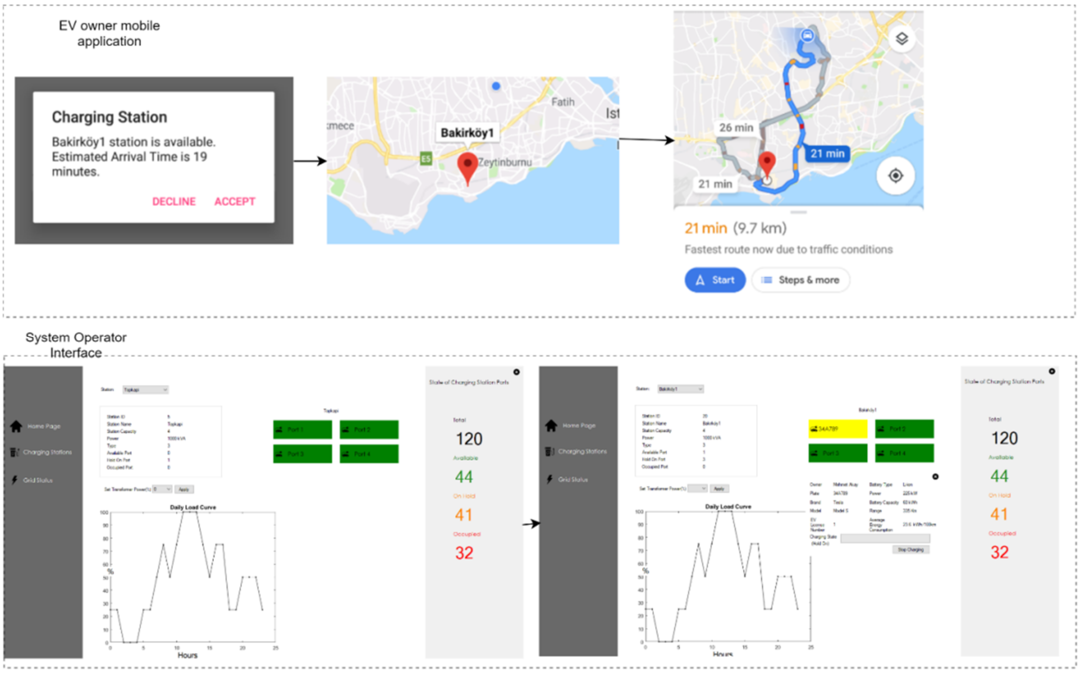

Fig. 8. The demonstration of the results for the second case.

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