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Charging Station Modeling of Electric Scooters Supported by Renewable Energy and Storage System

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Abstract **–** Today, due to environmental concerns and limited energy resources, electric vehicles are rapidly becoming popular. Therefore, developments in battery technologies and charging stations are an important factor for these vehicles to become more widespread. Increasing the number of stations offering fast charging will increase the number of electric vehicle owners or rental companies and enable more comfortable travel. Additionally, the use of energy obtained from Renewable Energy Sources (RES) will ensure that charging stations are environmentally friendly. In this study, technical and economic analysis of a small-scale RES and storage Electric Scooters (ES) charging station modeling was conducted at Marmara University Recep Tayyip Erdogan Complex (MURTEC) to support student intra-campus transportation. In the study, modeling was done with different Hybrid Power System (HPS) configurations, RES, and equipment manufacturers using Homer Pro software. Designs are optimized to find the system that performs best in each scenario. A comparative analysis was carried out between different systems in terms of carbon emissions and cost savings, among other parameters.

Keywords – Electric Scooters, Charging Station, Storage Management, HPS, HOMER

I. INTRODUCTION

As the world advances, electricity consumption is becoming increasingly crucial. Despite the limited supply of fossil fuels, systems that generate energy based on them can still produce enough electricity to meet the demand. Moreover, the combustion of fossil fuels leads to global warming and the emergence of long-term environmental issues [1]. Developing complementary alternative power sources to meet energy needs while reducing emissions is a research priority [2]. By comparing investment costs, the combination of sources that will meet the load demand is investigated, and the most suitable system is determined based on regional, environmental, and cost criteria [3]. The electricity grid can meet the highest demand by integrating renewable energy sources with traditional ones. Electric Scooter (ES) technology is currently a competitive alternative to the existing global transportation system due to effective energy management [4]. Factors such as high costs, limited range, and insufficient charging station infrastructure make the adoption of Electric Vehicles (EVs) challenging. The development of charging stations in sync with battery technologies will facilitate the widespread use of EVs [5]. An analysis has been conducted to highlight EVs as a clean energy alternative compared to vehicles using gas and fossil fuels. The study extensively examines how non-linear loads affect the power quality of EVs [6]. Das et al. (2019) have explored the current state of the EV market, standards, charging infrastructure, and the impact of EV charging on the grid in their study [7]. Technical solutions that promote the increase of electric vehicles, along with the collection and analysis of data from vehicles in a given region or passing through, can provide projections for future vehicle numbers and address potential issues [8]. In practice, EVs meet their electricity demands from the grid by charging in private places such as homes or parking lots. This puts additional strain on the existing electricity grid. Therefore, considering different types of energy production techniques as an energy source may be a viable option [9]. Research has investigated the voltage drop and imbalance issues created by EVs in the distribution system, depending on real traffic volume and average driving time. Simulations were conducted at various penetration levels, and the results were compared with standards [10-12]. Studies have been conducted specifically demonstrating how non-linear loads, such as EVs, affect power quality. They connected varying numbers of EVs to the power system and examined changes in power factor through simulations [13]. Many countries have started establishing electric transportation networks within the framework of climate change mitigation plans and incentive programs. In Turkey, the demand for electric vehicles is increasing due to their affordability and environmentally friendly nature [14].

All of the above studies are studies on charging station design or meeting the electrical load for automobile-style electric vehicles. Our study is a study carried out to meet the need for electric scooter charging stations with RES.

II. Materials and Method

This study was conducted in the MURTEC parking area with geographic coordinates 40°57'27.0" North, 29°08'09.2" East, as indicated in Figure 1. Analyses were performed in the geographic region specified. To determine an appropriate solution, a known economic approach was employed. This optimization approach can be used universally, taking into account meteorological conditions specific to the relevant area [15,16].

Fig. 1 Electric Scooter Charging Station Application Area.

A. *HPS Electric Load Profile*

In the area where the analysis will be conducted, efforts have been made to improve transportation and reduce traffic, along with attempts to minimize the carbon footprint. The design of the Hybrid Power System (HPS) envisions using Electric Scooters (ES) for transportation within the school campus to facilitate commuting. Details regarding the anticipated use of ES are provided in Table 1.

Table 1. Technical Data for Electric Scooters

Technical Specs	**Citymate X7**	**Xiaomi M365**	**Xiaomi M365 Pro**	**Segway Ninebot**
Motor	350 Watt	250 Watt	300 Watt	250 Watt
Battery	5000 Ah	7800 Ah	12800 Ah	5200 Ah
Weight	12.5 kg	12.5 kg	14.2 kg	11.3 kg
Range	25 km	25 km	45 km	20 km
Speed	25 km	25 km	25 km	25 km
Charging	5 h	5 h	8.5 h	3.5 h
Drive	Front	Front	Front	Front

The distance within the campus, from one end to the other, is approximately 1 km, and when considering the route of Electric Scooters (ES) as a round trip, it is calculated to be 2 km. It is assumed that the ES, which will provide transportation, will draw an average load of 0.5 kW. Assuming they undergo at least two charging cycles per day, each ES would require a minimum of 1 kW of power. With a total of 50 ES, when the daily load is calculated as 50 kWh per hour and an average usage time of 12 hours per day, the hourly transportation demand for one ES is approximately 5 kWh. The monthly energy consumption graph of the High-Passenger Shuttles (HPS) is provided in

Figure 2, based on student density within the campus.

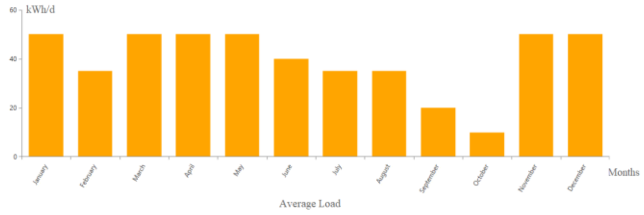

Fig. 2 Monthly energy consumption graph.

B. PV System

Solar radiation is a proportional estimate of the total energy reflected onto the panels by the total area. The total amount of energy is dependent on the angle, the distance between the sun and the earth, climatic conditions, and mostly, time. The total radiation amount for each month, based on the location where the Hybrid Power System (HPS) is designed, is indicated in Figure 3.

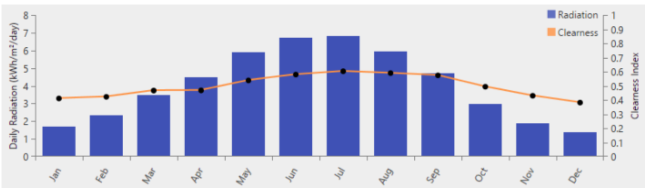

Fig. 3 Average Global Horizontal Irradiance (GHI) and Clearness Index data for Marmara University.

The daily horizontal radiation incident on the horizontal plane, depending on the Clearness Index (CI), is influenced by the structure of the sun. For the envisaged installation area, the average daily solar radiation value is specified as 4.02 kWh/m²/day [17]. To meet the calculated load obtained from the calculations, a small-scale 4 kW PV system has been installed within the HPS. The system is designed to be addressed with 10 units of domestically branded solar panels, each with an output of 400 W, to fulfill the power requirement. Considering the data, it is observed that the region is suitable for PV installation. The power output of a PV array is calculated as per Equation (1) [18].

$$P_{PV} = Y_{PV} \, . f_{PV} \, . \frac{G_T}{G_{T,stc}} \, . \left(1 + \propto \, . \, \left(T_C - T_{C,stc}\right)\right) \quad (1)$$

In this equation;

P_{PV} PV generated power (kW),
Y_{PV} PV generated power at STC (kW)
f_{PV} loss factor of PV array (%),
G_T solar irradiance (kW/m^2),
$G_{T,stc}$ solar irradiance at STC (1 kW/m^2),
α power temperature coefficient (-0.485%/◦C),
T_C PV cell temperature (◦C)
$T_{C,stc}$ PV cell temperature at STC (25 ◦C).

The efficiency of a PV series is calculated as in Equation (2) [19].

$$\eta_{stc} = \frac{Y_{PV}}{A_{PV} \, . \, G_{T,stc}} \quad (2)$$

In this equation;

η_{stc} PV panel efficiency (%),
Y_{PV} rated capacity of the PV array (at standard test conditions),
A_{PV} surface area of PV panel (m^2),
$G_{T,stc}$ solar irradiance at STC (1 kW/m^2).

C. Wind Energy Potential

MURTEC is situated at an elevation of 100 meters above sea level in a region with high wind intensity. According to wind measurements, it has been positioned at the parking area, as highlighted in Figure 1. For the location area, wind maps published by the national meteorological authority indicate an average wind speed ranging from 3 to 10 m/s at a height of 100 meters, as shown in Figure 4, detailing the monthly average wind intensity measurements.

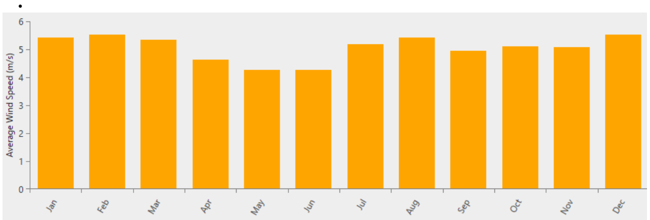

Fig. 4 Average wind intensity for Marmara University.

In this study, we utilized a single wind turbine with a hub height of 17 meters and a total output power of 1 kW, chosen for its suitability to the specific conditions of the location. The first feature provided by the software used, illustrated in Figure 4, is the Weibull distribution for wind speed, which gives the highest frequency of occurrences for wind speeds between 5 and 8 m/s. In addition to nominal power, the software also provides specifications such as maximum power, cut-in wind speed, nominal wind speed, and rotor diameter. Accordingly, the region is suitable for the installation of a small-scale, high-wind-power turbine. The power output of a wind turbine is calculated as per Equation (3) [20].

$$P_{WT} = P_{WT,stc} \cdot \frac{\rho}{\rho_0} \tag{3}$$

In this equation;
P_{WT} wind turbine generated power (kW),
$P_{WT,stc}$ wind turbine generated power at STC (kW),
ρ real air density (kg/m^3),
ρ_0 air density at standard temperature and pressure (1.225 kg/m^3).

The wind speed equations affecting a wind turbine are calculated as per Equation (4) [21].

$$\frac{u_{hub}}{u_{anem}} = \left(\frac{z_{hub}}{z_{anem}}\right)^{\lambda} \tag{4}$$

In this equation;
u_{hub} wind speed at the height of the wind turbine (m/s),
u_{anem} wind speed at anemometer height (m/s),
z_{hub} wind turbine hub height (m),
z_{anem} anemometer height (m),
λ force factor.

D. *Converter*

In renewable energy systems, converters play a crucial role by transforming the power transferred to the DC bus into AC power, integrating it into the AC load bus, and representing the power output that feeds the ES in the designed Hybrid Power System (HPS) [22]. A 5 kW converter has been employed in the designed HPS based on peak power.

E. *Battery Energy Storage Systems*

A Battery Energy Storage System operates through reversible chemical reactions to carry out charging and discharging processes. Essentially, during charging cycles, incoming electrical energy is converted into chemical energy for storage, and during demand periods, this energy is then converted back into electrical energy for final use [23]. Globally prevalent battery technologies include Lithium-Ion (Li-Ion), Lead-Acid, Sodium Sulfur, and Vanadium Redox. In this study, Li-Ion batteries will be used [24]. Lithium-ion technologies exhibit excellent performance characteristics, are highly flexible and scalable, enabling them to have a broad range of applications. As a sub-product in this study, fifteen Nanogel brand gel-type batteries with a voltage of 12 V and a capacity of 100 Ah each have been selected. Thus, considering climatic conditions, the most effective solution has been produced. The capacity value of the battery is given in Equation (9) [25].

$$N_{BAT} = \frac{C_{Wh}}{C_{BAT}} \tag{9}$$

In this equation;
N_{BAT} number of batteries (number),
C_{Wh} battery pack capacity (kWh),
C_{BAT} battery capacity (Ah).

F. *Homer Software*

HOMER (Hybrid Optimization Model for Multiple Energy Resources) integrates three powerful tools for the collaborative operation of engineering and economics into a single software product: briefly, it is a simulation model. It endeavors to simulate a feasible system for all possible equipment combinations you may consider. Depending on how you design it, the HOMER program can simulate hundreds or even thousands of systems with time steps ranging from one minute to one hour, throughout the entire year, for the operation of a hybrid microgrid [26]. Economic Analysis: The net present cost (NPC) includes the installation and operating costs incurred over the lifetime of the system. The economic outputs of the system are calculated to determine the net present cost. The net present cost is calculated using Equation (15).

$$NPC = \frac{C_{ann,total}}{CRF(i,N)} \tag{15}$$

In this equation;
NPC net present cost ($),

$C_{ann,total}$	total annualized cost ($/year),
$CRF(i,N)$	capital recovery factor (1/year).

HOMER defines the unit energy cost as the average cost per kWh of useful electric power generated by the system and explains it with the formula in Equation (17).

$$COE = \frac{C_{ann,total}}{E_{AC} + E_{DC} + E_{grid}} \tag{17}$$

In this equation;
COE levelized cost of energy ($/kWh),
$C_{ann,total}$ total annualized cost ($/year),
E_{AC} primary AC load served (kWh/year),
E_{DC} primary DC load served (kWh/year),
E_{grid} total grid sales (kWh/year)

III. SIMULATION

In this study, the simulation has been conducted taking into account current technology and developments. An illustrative application on electric vehicle charging, including the charging interaction between the charging station and the vehicle, has been implemented using the HOMER program. Economic analyses have been performed on the application, considering real-world values and tailored to fit the infrastructure of Turkey.

A. Modeling of HPS

HPS elucidates its components and the assumptions adopted for the enhancement of this study. Figure 5 indicates the design diagram of the Electric Scooter Charging System (ESCS), Grid, Photovoltaic Panels (PV), Wind Turbine (WT), Battery Energy Storage System (BESS), and the design layout for two different locations where ESCS will be installed, used in the simulation.

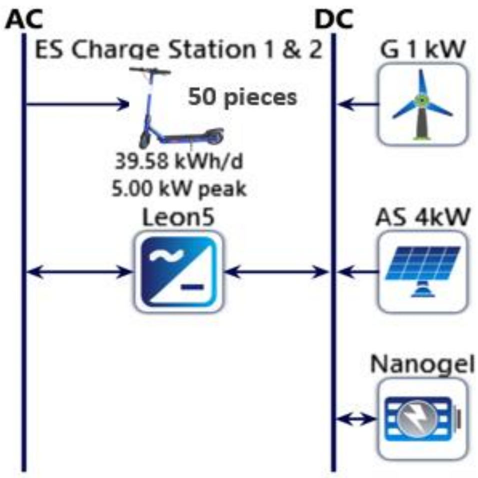

Fig. 5 Simulation Application Diagram

The electricity generated from PV and wind energy systems is converted to Alternating Current (AC) through a converter and sent to the ESCS independently of the grid. When there is no load in the ESCS or the drawn load is lower than the energy production from PV, the storage system is charged [27-29]. The BESS supports ES charging by supplying power when there is no energy production with HPS or when it is insufficient. Conversely, when there is excess energy production with HPS, the storage system is charged [30,31].

B. Electricity Generation in HPS

Using HOMER Pro software, the annual energy production of each wind turbine, solar panels, and storage system was evaluated. Considering the yearly data, all the energy generated from RES was converted from DC to AC with the help of inverters. The efficiency of the grid inverter was assumed to be 95%. Figure 6 illustrates the annual average electrical power production provided by HPS for ESCS according to the months.

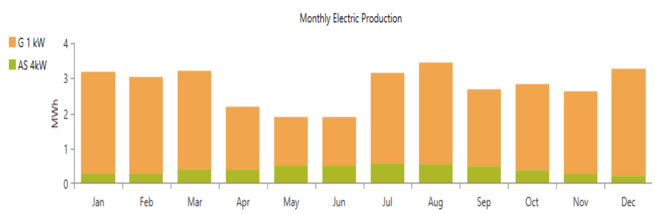

Fig. 6 Annual average power production of HPS by months.

When considering a daily consumption need of 50 kWh/d and including 18 kWh/d from the BESS, we have a power cycle of 68 kWh/d for the off-grid HPS. Throughout the year, there is an annual production of 4970 kWh/yr with the PV system and 28489 kWh/yr with the WT. Additionally, excess energy production, varying with months of lower student population, is calculated as 33459 kWh/yr. The estimated power demand for ES is an average of 14443 kWh/yr. The surplus of generated electrical energy is 17310 kWh/yr. Depending on the selected brand of ES, the excess electrical energy can be consumed within the HPS.

C. Emission Status of HPS

Emission values can be easily calculated in the HOMER software. Before simulating the power system, HOMER determines the emission factor (pollutant emitted per unit fuel consumed) for each pollutant. After the simulation, it multiplies the emission factor by the total annual fuel consumption to calculate the annual emission of that pollutant [28]. The energy amount produced annually from RES by our EPS is 33459 kWh. If this energy were supplied from the grid using conventional fuels, it would result in approximately 57.84 kg of greenhouse gas emissions per day, 21146 kg/year of SO_2 emissions, and 44.85 kg/year of NO_2 emissions being released into the environment, causing environmental pollution. Opting for the recommended HPS ensures no greenhouse gas emissions, and it will be a zero-carbon footprint, renewable, clean, and environmentally friendly HPS-connected ESCS.

D. Cost of HPS

In this study, as seen in Table 2, the required HPS solution has been evaluated economically. This modeling provides an assessment for a potential ESCS intended to be implemented.

Table 2. The Economic Aspects of the System

No	Parameter	Value
1	Internal rate of return (RR)	13 %
2	Return of Investment (ROI)	10 %
3	Simple Payback	7-8 years
4	NPC	$107,209
5	Operating Cost	$910.05
6	Levelized Cost of Energy (LCOE)	$0.6410

IV. CONCLUSION

As a result, developments in ES battery technologies and charging stations are important development areas that can provide environmental benefits and create economic opportunities. The development and dissemination of these technologies and the creation of infrastructure are important to ensure a more sustainable transportation system in the future. When the data obtained as a result of the application is examined, it is seen that ES electrical energy is provided and even extra electrical energy is produced thanks to the electricity obtained with 100% RES. This excess energy produced can also be used in parking lot lighting. When this study is made applicable, it will provide both time-saving and ease of transportation, especially for students, on campus transportation. In addition, since the study is exemplary, it is thought that it will contribute to future studies on this subject.

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