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Mitigating Load Burden on Smart Grid via EVs: A Case Study on Harnessing EVs as Mobile Battery for Society

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***Abstract*---**World energy consumption is quickly rising as a result of population and economic expansion, particularly in big emerging economies, which will account for 90% of energy demand increase through 2035. Electric vehicles (EVs) are critical components of the electrification revolution aimed at reducing the carbon footprint. In this case study, a completely different side of EVs is explored where EVs can be used as an energy storage unit that has the potential to meet the demands of high energy needs in a variable electricity tariff setting. The study proposed in this work suggests that energy stored in EVs can also be used back in the smart grid at the time of high energy requirements which can significantly decrease the load shedding in both urban and rural areas. The simulation model presented on MATLAB shows a significant dip in energy demand after electricity stored in the Electric vehicles is used back in the smart grid. The study also proposed an ensemble model that is able to predict the overload in the Grid. The ensemble model achieving the R2 score of 0.87 and RMSE value of 0.06. The prediction done by the ensemble model can be used to send the notification to the EVs driver present in the nearby location.

***Keywords*---**EVs, V2G, Ensemble Model, Regression Prediction, Prosumer.

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Introduction

th rising energy costs, worries about energy security and fossil energy supplies, and a growing consumer base, environmental and climate change issues and laws are becoming increasingly important. Electric vehicles are beginning to arrive, contrary to forecasts worldwide.[1]

The objective of this case study is to provide a solution for the rising energy demand in both urban and rural environments by using EVs as mobile storage system. The case study suggests that the use of EVs in the variable energy tariff setting can ease the load on the smart grid. Electric vehicles may serve as either loads or distributed energy suppliers in a concept known as vehicle-to-grid (V2G)[2]. The V2G idea has the potential to improve the electrical grid's efficiency, stability, and reliability. A V2G-capable vehicle can provide reactive power assistance, active power regulation, tracking of variable renewable energy sources, load balancing, and current harmonic filtering. These technologies can provide auxiliary services like as voltage and frequency control and spinning reserve [3]. V2G expenses include battery deterioration, the demand for intense communication between automobiles and the grid, effects on grid distribution equipment, infrastructure upgrades, and social, political, cultural, and technological hurdles. Vehicle owners and grid operators should find V2G operation to be more cost-effective[4]. This article looks at the benefits and cons of V2G technology for individual cars as well as fleets of vehicles.

A substantially lesser number of studies address the relevance of evaluating environmental and climatic elements of a V2G transition, as well as the role of consumer tolerance and knowledge of V2G systems. Exploratory study on natural resource utilisation and externalities, discourses and narratives, as well as concerns of social justice, gender, and urban resilience, is also necessary [5]. These research gaps must be solved if V2G is to accomplish the desired societal transformation.

Figure 1 shows the process flow of the proposed approach, in step 1, when the tariff is low during the non-peak hour, charging of EVs can be done during the period of low energy demand. In step 2 during the high tariff, electric vehicle drivers get a notification on their mobile devices about the recent hike in the tariff during peak hours. This tariff vary location to location and time to time. Those electric Vehicle drivers who are free at that moment and wants to get the benefit of high tariff incentive scheme can reach to their nearest grid system and initiate step 3 which is using their electric vehicle batteries to feed the electricity back to the smart grid system high energy demand.

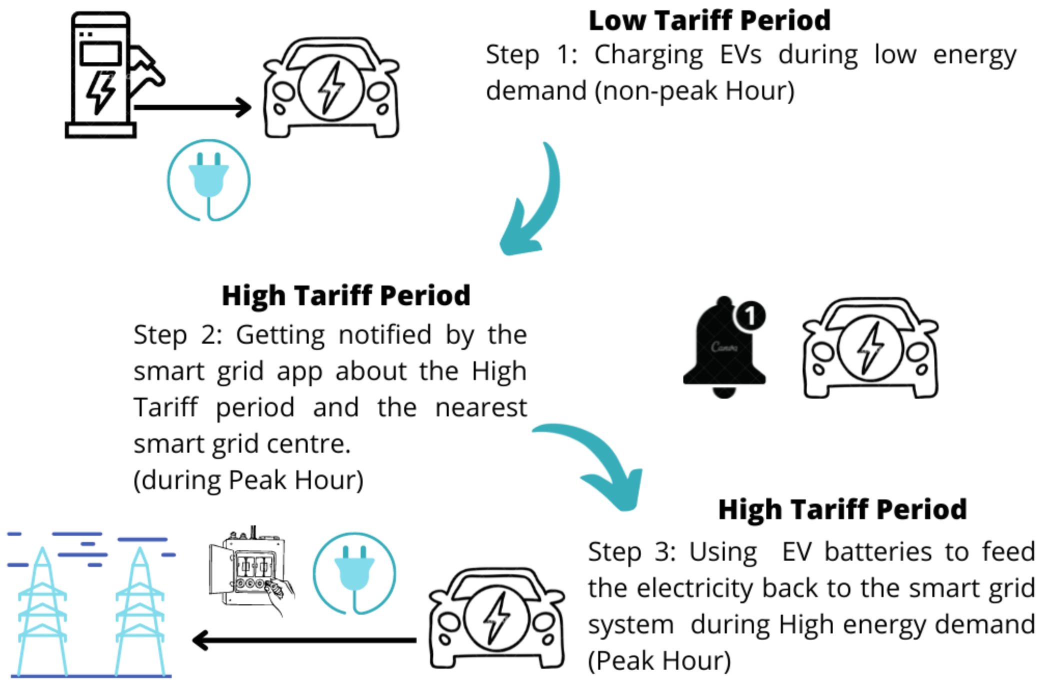

Figure 1: Process flow of case study

Related work

Hayajneh et al., 2021 [6] proposed a strategy of merging stationary and mobile applications of battery energy storage systems constructed within renewable energy farms to minimise renewable power curtailment and stimulate grid-scale energy storage deployment. Miller et al., 2020 [7] collected the hourly grid data in the US and estimated EV usage emissions in 60 cases across the United States using hourly grid data from 2018 and 2019 (along with hourly charging, driving, and temperature data). It was reported that Light-duty automobiles account for 20% of net US greenhouse gas emissions. The use of electric vehicles (EVs) can help to minimise these emissions. The influence of charging patterns on emissions varies by location. Overnight EV charging creates 70% more and 20% less emissions than daytime charging in California and New York, respectively.

Sovacool et al., 2018 [5] did a systematic review of 197 peer-reviewed publications published on V2G between 2015 and early 2017 and noticed that the majority of V2G studies undertaken during that time period concentrated on technical aspects of V2G, such as renewable energy storage, batteries, or load balancing to lower power prices, with environmental goals serving as constraints in certain cases.

Case study: using EVs as Mobile battery

Experiments/simulation

To validate the proposed topology of an electric vehicle, a model was simulated in MATLAB environment as shown in Fig 2. In this model electric vehicle is used to transfer reactive power to the grid to compensate for the low-voltage profile at the load end and reduce the effective loading on the grid. Prior to the availability of EV, the voltage at the load end is low and the grid is overburdened. If such kind of scenario prevails for a duration of more than 2 sec, then the system is bound to take alternative actions, which may include, load shedding or tripping of load. Usually, nowadays all the loads connected at the consumer end are drawing constant power and such kind of low voltage profile results in maloperation of the equipment and the cascading effect of this may also cause harm to the individuals who may be operating this equipment or are in the vicinity of such equipment, which may sometimes may also result in a loss of life.

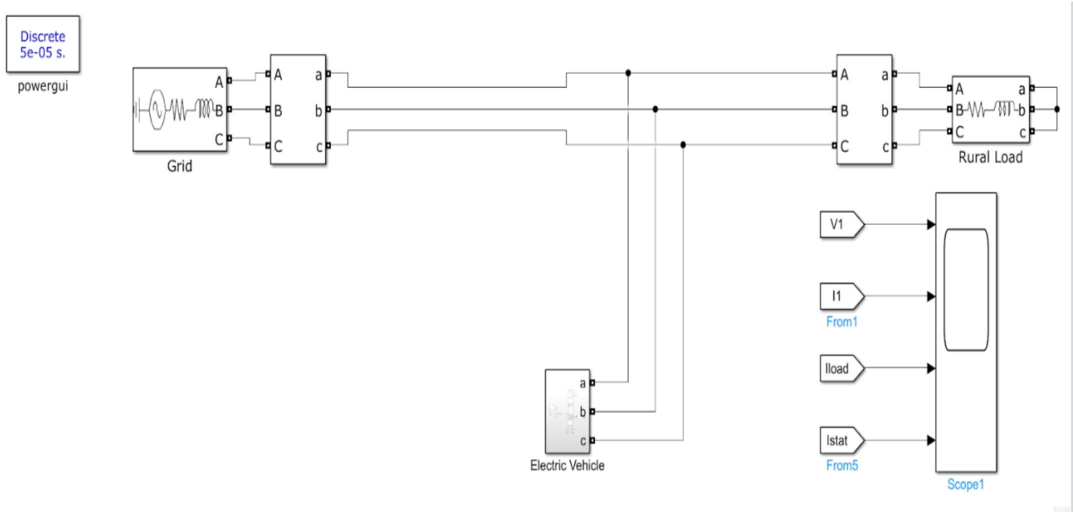

Figure 2: Figure showing the inclusion of electrical energy from EVs into the smart grid

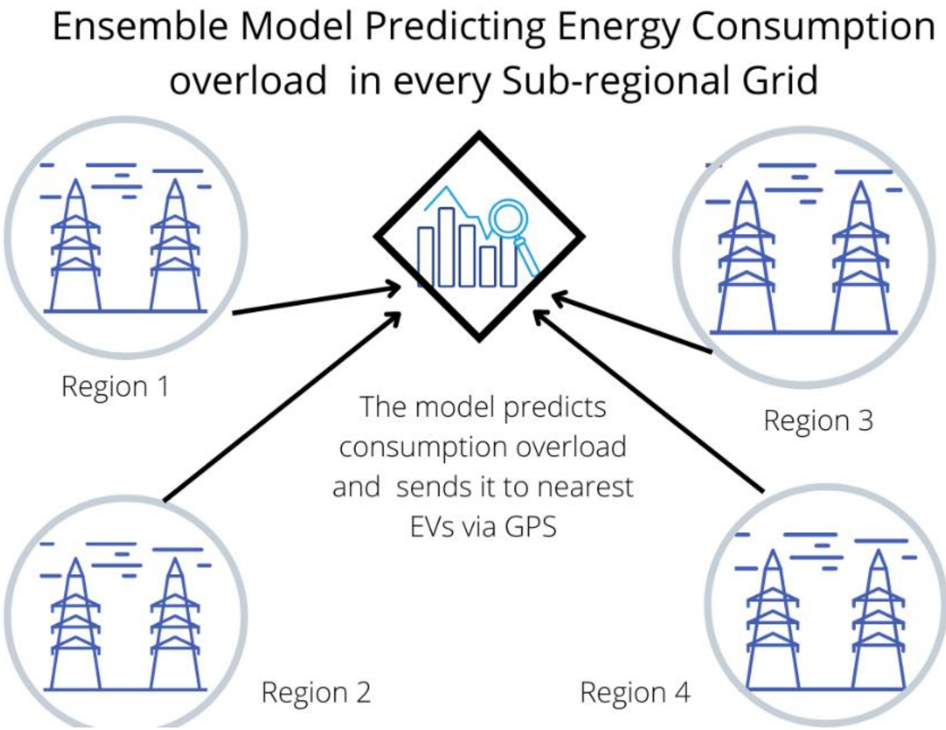

Figure 3: Notification module demonstrating the functionality of ensemble model that triggers the notification on the application of nearby EV user/driver

Secondly, An Ensemble model is being developed that can predict the energy overload 3 hours before the Overload event. An Ensemble model is based Random forest algorithm trained on the US grid hourly dataset curated by Miller et al., 2021 [7].To predict the overload event first, the overload threshold is being set for every local grid station as shown in Fig 3. The overload Threshold varies from one local grid to another based on its capacity. The real-time time-series dataset is being used as an input for the ensemble model [8]. The job of the ensemble model is to predict is to estimate the consumption of electricity in that local region after 3 hours using the random forest regressor. Once the 3-hour prediction done by the model crosses the overload threshold then the system emits distress signals to the app users in the nearby area. Users involved in this pilot program can be given electricity tariffs at incentivised rates.

Results

This section shows the result of experiments that was done in the previous section. Figure 4 demonstrates the result of simulation model performed on MATLAB. It reveals the extent of dilution of load with the inclusion of electricity that was provided in the grid by electric vehicles. Figure 5 shows the plotted result of the random forest regressor model. The graph shows predicted load on y axis and the actual load on x axis. the model was evaluated on various parameter like Mean Error (ME),Root Mean Square Error (RMSE), mean absolute error (MAE) and R2. It is having R2 score of 0.87, MAE of 0.04 and RMSE of 0.06.

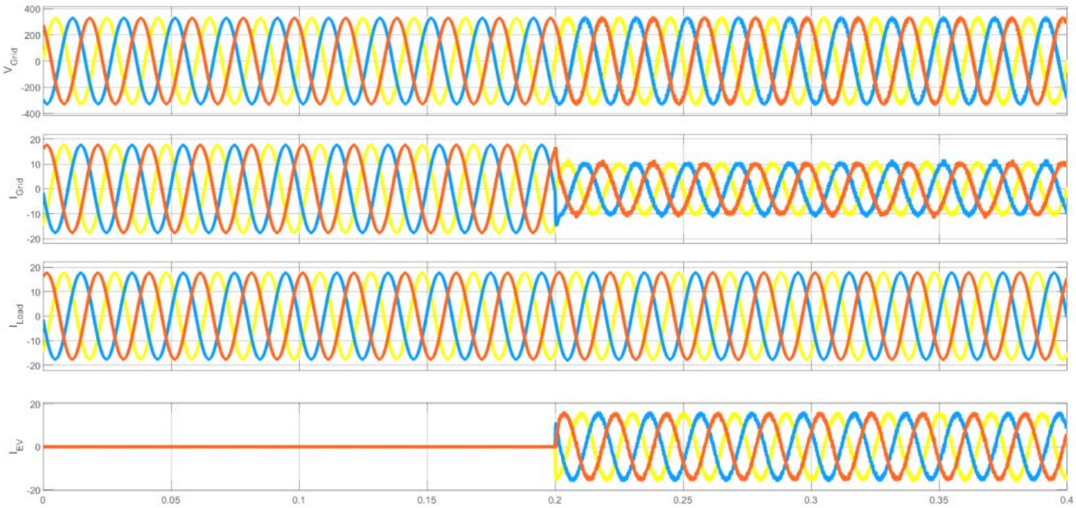

Figure 4: Simulation results showing the dilution of load with the inclusion of electricity in the Grid by EVs

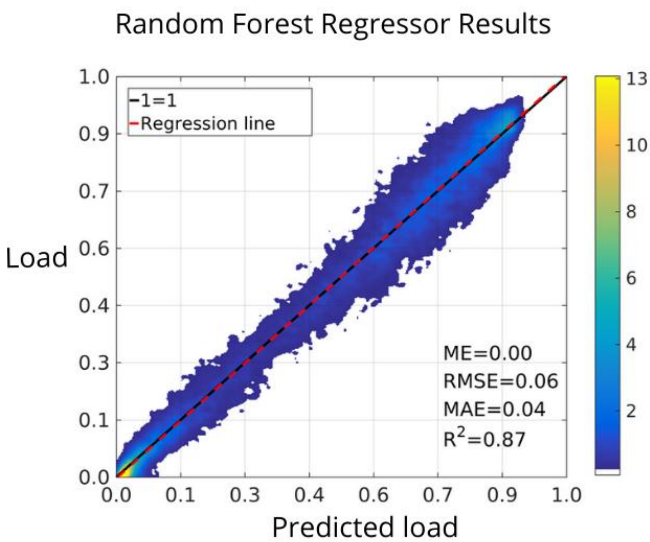

Figure 5: Ensemble model results showing various evaluation parameters ME, RMSE, MAE, R2

Conclusion and future work

This goal of this case study is to demonstrate the scenario where energy stored in EVs can also be used back in the smart grid at the time of high energy requirements which can significantly decrease the load shedding in both urban and rural areas. The simulation model presented on MATLAB shows a significant dip in energy demand after electricity stored in the Electric vehicles is used back in the smart grid. The study also proposed an ensemble model that is able to predict the overload in the Grid. The ensemble model is achieving the R2 score of 0.87 and RMSE value of 0.06. The prediction done by the ensemble model can be used to send the notification to the EVs driver present in the nearby location. We will also try to minimise this RMS error by incorporating different optimization techniques like pruning, bagging, and boosting. Moreover, we can also use different machine learning and deep learning models to improve the accuracy of the model

As soon as the EV is connected to the point of common coupling (PCC), EV shares some part of load from the grid and the voltage profile at the load end is restored to the standard value. This is evident from the decrease in the current from the grid. Thus, with the application of EV, the low voltage and poor power quality profile at the load end is eliminated. Moreover, the application of EVs may result in economic benefits to consumers (now prosumers), stable power availability, and high quality of power, resulting in a state of consumer satisfaction and sustainable growth of society.

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