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Energy Transferring Technology for Electric Vehicle Charging Station Considering Renewable Resources

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***Abstract*— The rapid expansion of the Electric Vehicle (EV) industry is occurring in the world owing to numerous economic and environmental benefits. However, a lack of charging infrastructures could make EV charging quite difficult. Besides, the EV owners recharge the batteries from the residential connection which leads to power quality problems as well as increased system loss. It is known that renewable like solar-based EV charging stations lowers the burden of the utility grid in an eco-friendly way. However, solar irradiation lasts only for few hours a day while EV charging especially in Bangladesh starts from peak hour. Therefore, hybridization of solar with largely available biogas resources in Bangladesh can be a potential solution to overcome the EV charging disputes. To make the EV charging station more effective, reliable, and robust, energy transferring technology like Grid to Vehicle (G2V) and Vehicle to Grid (V2G) in Bangladesh incorporating renewable resources can be implemented. In this paper, V2G and G2V technology for EV charging are proposed using a fuzzy inference system that ensures cost-effective EV charging with lowering peak hour demand. The proposed EVCS offers a real-time charging cost which inspires the EV owners to recharge the batteries during the off-peak hour with the lowest cost.**

Keywords— EV Charging Station (EVCS), Grid to Vehicle (G2V), Vehicle to Grid (V2G), Renewable Resources, Fuzzy Logic

I. Introduction

Owing to the several socio-economic and environmental benefits, EVs are significantly increasing in the world. However, the Electric Vehicle Charging Station (EVCS) is not sufficient in different countries, mostly in developing countries [1]. Therefore, the EV owners in those countries are recharging batteries from the residential connection at a lower tariff which further decreasing the profitability index of the power sector [2]. Besides, the huge number of EV chargers i.e. non-linear loads connected to the distribution network in an uncoordinated and haphazard way, are affecting power quality which results in technical and economic problems [3]. Researches performed on renewable integrated EV charging claimed that it improves power quality by lessening the burden of the utility grid in a low-cost and environment-friendly way [4, 5].

The huge potentiality of solar energy is treated as the best option for EV charging, although solar irradiation is effective for limited hours in a day. Consequently, during the night, rainy and foggy environments, solar irradiation is absent and unable to participate in electricity generation. In this circumstance, available biogas resources can be utilized for generating electricity as well as ensuring proper waste management. Hence, to establish reliable and secure electricity generation for EVCS, hybridization of these resources can be a more accepted option [6].

Electric Vehicle charging station based on hybrid renewable resources can be utilized further for integration of energy transferring technology i. e. Grid to Vehicle (G2V) and Vehicle to Grid (V2G). Various researches were conducted on energy transferring scheme based on solar and wind resources [7-8]. However, solar and biogas-based EVCS with an energy transferring scheme is not performed yet. Therefore, in this research energy transferring system i. e. G2V and V2G is proposed considering hybrid renewable resources. Furthermore, the variations of charging cost with respect to renewable power generation, EV power demand, and time of use (Peak/off-peak hour) are analyzed.

The main objective of this research is to develop an energy transferring scheme from the utility grid to vehicles and vice versa for increasing EV charging station performance by reducing charging cost and increasing power availability incorporating renewable resources.

II. PRESENT STATUS OF EVCS IN BANGLADESH

In Bangladesh, the rise of EV use is making threats to the power sector as this sector consumes 500 MW of electricity daily. Besides the lack of sufficient EV charging stations inspires the EV owners to recharge the batteries at home which further leads to system loss. Although the Government of Bangladesh sets an individual charging rate for EV the EV charging at residential connection would be made this problematic. Only a few solar charging stations were established in different corners of the country, however, due to intermittent behavior of the solar resources the power generation is low and it needs storage devices which increases the charging cost. In Bangladesh, the EVCS uses a Level 2 charger which operates on 208-240 V with AC power rating 3 kW-19 kW. Usually, this type of charging requires 8 hours for being fully charged. Moreover, most of the EV in Bangladesh goes to charging station especially on the peak-hour period which hampers power quality [9].

Fig. 1 shows a typical EVCS in Bangladesh where all the EVs recharged the batteries from utility grid. Therefore, only one way energy transferring is possible. But the EV charging station based on renewable like solar resource can produce surplus energy which can be transferred to the utility grid. If both directional energy transfer takes place, the charging station performance certainly improved.

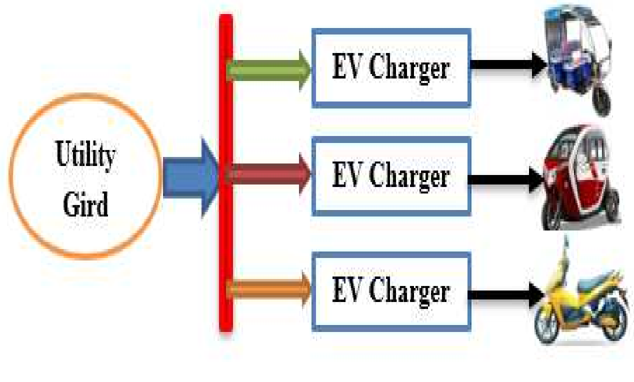


Fig. 1: Typical Electric Vehicle Charging Station in Bangladesh.

A. *Renewable Resources in Bangladesh: Solar and Biogas*

The electricity generation sector in Bangladesh is expanding and the government is also trying to achieve cost-effective, energy efficient and environment friendly structure by using available renewable resources like solar, biogas, wind and so on. The average insolation in Bangladesh is about 5 kWh/ m^2/day and effective duration for solar irradiation exists for 4-5 hours in a day [6]. These scenarios indicate that Bangladesh has a good prospect for solar power generation. The renewable energy-based power generation has installed capacity of 722.60 MW in Bangladesh. In Bangladesh already 4.5 million solar home systems are installed and every year more than 65,000 solar home systems are installing throughout the country [10].

As it is known, the average waste generation per people in Bangladesh is 0.5 kg and therefore as a populated country like Bangladesh there is a huge probability for generating electricity from this sector [11]. Moreover, the Bangladesh government is also implementing 1 MW biogas plant in Keranigonj, Dhaka. Lots of off-grid biogas plants are installed in the whole country by Infrastructure Development Corporation Limited (IDCOL). However, solar-biogas based hybrid power generating station is not established in Bangladesh as it increases energy generation through economic and efficient way. Table 1 shows the prospects of renewable energy resources i.e. solar, hydro, wind, biogas/biomass etc. in Bangladesh.

Table 1: Renewable Energy prospects in Bangladesh [10]

Renewable Source	Off-grid (MW)	On-grid (MW)	Total (MW)
Solar	346.58	142.10	488.67
Wind	2	0.90	2.90
Hydro	0	230	230
Biogas to Electricity	0.63	0	0.63
Biomass to Electricity	0.4	0	0.40

III. ENERGY TRANSFERRING SCHEME FOR EVCS

In this section, energy transferring model is proposed for EVCS considering renewable resources. First part will explain the proposed model of energy transferring technique and second part will describe the MATLAB simulation.

A. *Proposed model of the energy transferring scheme*

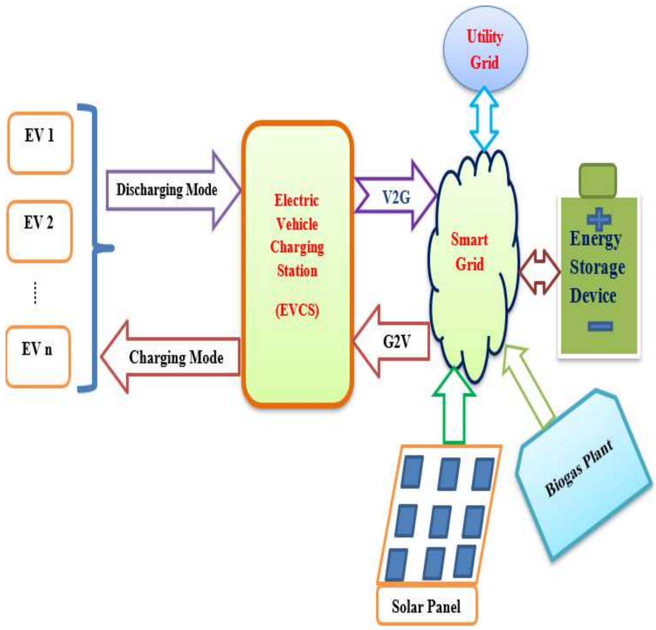


Fig. 2: Proposed Energy Transferring Scheme of EVCS considering Renewable Resources.

In this paper, solar and biogas resource are added as renewable. Energy storage device, utility grid and renewable power sources are integrated in the smart grid system. When EV power demand increases and the renewable power generation does not meet the demand then EV takes power from the utility grid called as Grid to vehicle (G2V). Also, charged EV batteries can transfer energy to the utility grid during its idle condition for meeting peak load demands which is referred as Vehicle to Grid (V2G) technology. Depending upon the demand, the EV batteries can charge or discharge power, hence, it could be used as moving storage device. The bi-directional power transfer mechanism is controlled by the algorithm developed within smart grid network. As such energy transferring system requires power electronic converters which plays vital role to the system due to the interconnection between the utility grid and the EV batteries. In this system, bidirectional AC-DC and also bi-directional DC-DC Converter is needed.

B. *Mathematical Modeling of Proposed Energy Transferring system*

The EV power demand depends upon the battery capacity, State of Charge (SoC), and duration of charging. Hence, the EV demand can be displayed as in equation (1).

$$P_{EV} = \frac{C_{Batt} * (SOC_{\max} - SOC_{\min})}{T_D}; \qquad (1)$$

The equation (2) shows the duration of charging of EV.

$$T_D = \sum_{t_{C,start}}^{t_{C,stop}} T_{departure} - T_{arrival} - T_{waiting}; \qquad (2)$$

The gross power demand of the EVs is the summation of individual power demand of all EVs which likely signifies as in equation (3).

$$P_{Gross} = \sum_{N=1}^{N} P_{EV}; \qquad (3)$$

Renewable Power is comprised of solar and biogas, hence, it can be written as,

$$P_{\mathrm{Ren}} = P_{Solar} + P_{Bio}; \qquad (4)$$

EV Charging mode:

When $P_{Gross} \leq P_{\mathrm{Re}\,n}$; then EV takes power from EVCS through smart grid. This time power not come from utility grid if renewable power capable to recharge the EV batteries.

EV discharging mode:

When EV is in idle mode, then the EV battery can be discharged through EVCS to smart grid for selling it to the utility grid. During discharging mode, $P_{Gross} < P_{\mathrm{Re}\,n}$.

C. MATLAB Simulation for the Proposed EVCS

In case of proposed energy transferring system, authors used Mamdani Fuzzy rule-based algorithm consisting three input variables of Renewable Power Generation, EV power demand, and Time of use as input variables where Energy transferring mode, and charging cost are output variables.

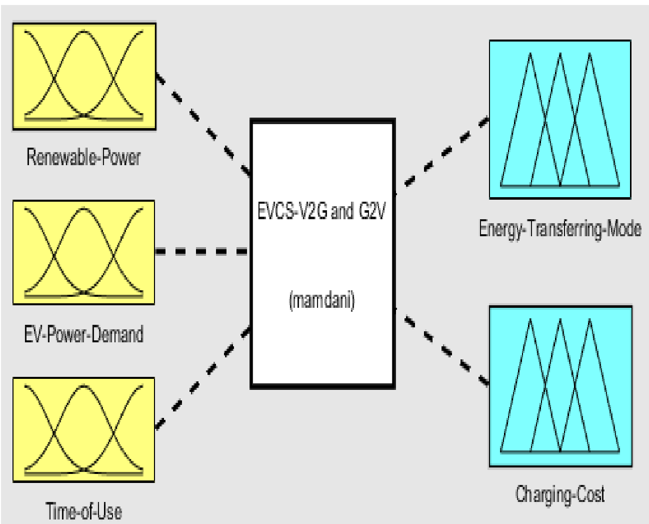


Fig. 3: Fuzzy Inference System of the Proposed System.

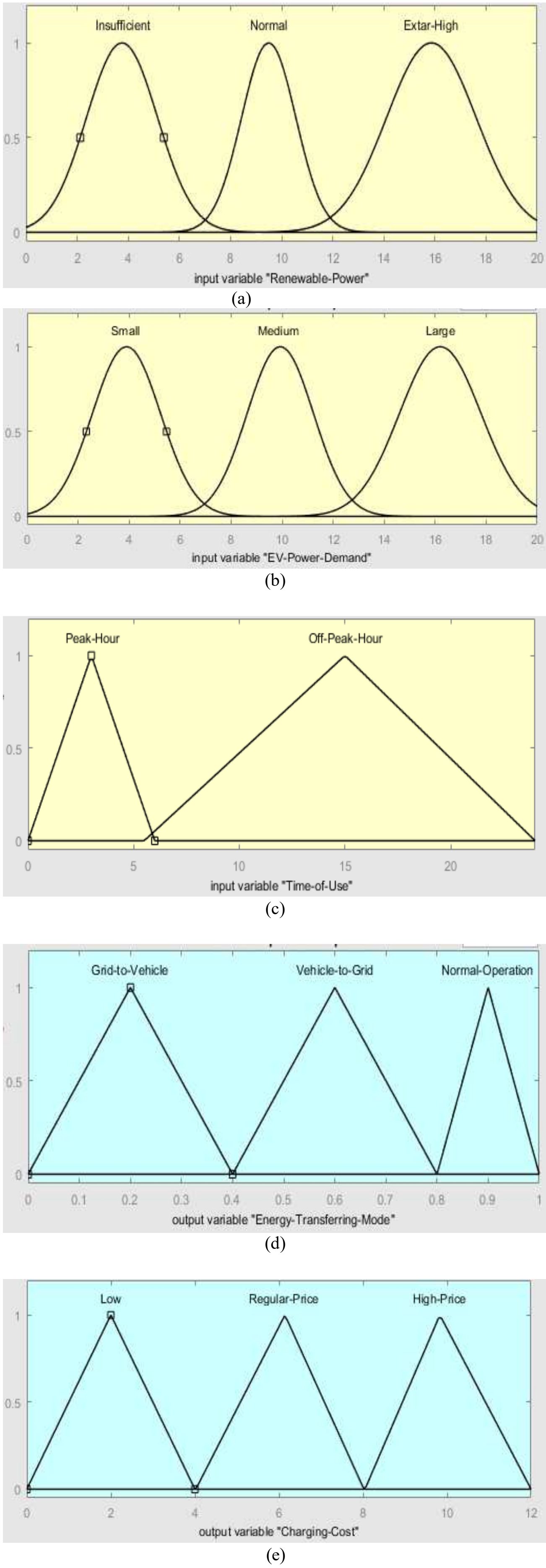


Fig. 4: Membership functions of input and output variables.

In this mamdani fuzzy system in fig. 3, centroid based defuzzification method is used. Also, in fig.4, (a), (b), (c) shows membership functions of all input variables whereas (d), (e) demonstrates membership functions of all output variables. Renewable Power has three gaussian membership functions named as insufficient, normal and Extra-high. EV power demand has also three gaussian membership functions categorized as low, average and large.

Time of use is divided into two membership function such as peak hour and off-peak-hour. On the other hand, energy transferring mode has three triangular membership functions for grid to vehicle mode, vehicle to grid and normal operation mode. Moreover, the charging cost has three triangular membership functions classified as Low price, Regular price and High price.

IV. Results and Discussion

In this section, energy transferring mode and charging cost is analyzed using fuzzy rule-based algorithm.

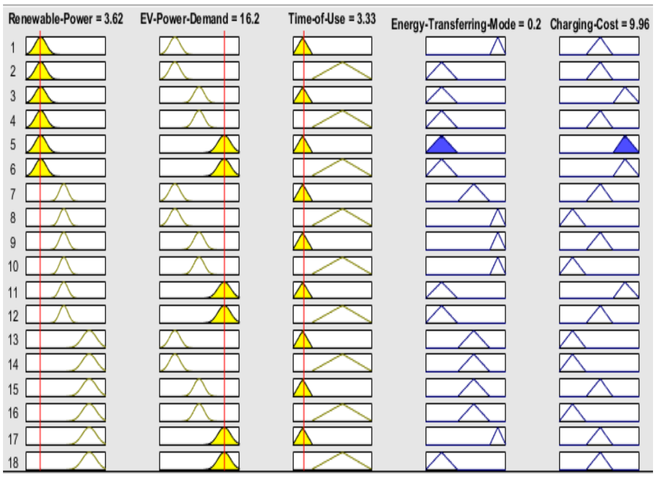
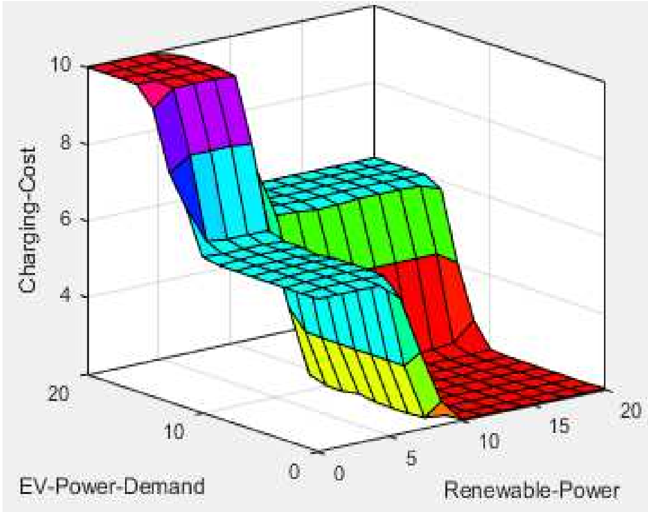


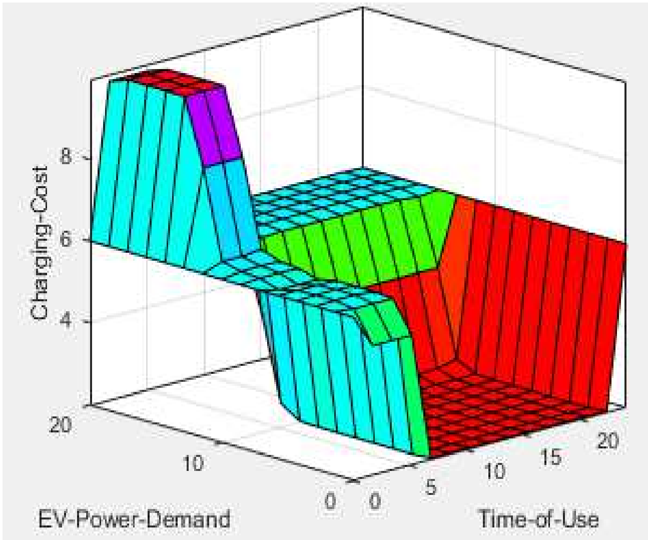
Fig. 5: Fuzzy Rule Viewer.

Fig. 5 shows a fuzzy rule viewer where eighteen (18) if -then rules are applied for three input variables and two output variables. When the renewable power generated by solar and biogas resources are low, EV power demand is high, time of use is in peak hour then the EV takes power from the utility grid with high price (Grid to Vehicle Mode). On the other hand, when sufficient renewable power is produced but the EV charging demand is lower then, the energy can be transferred to utility grid or nearby residence which is treated with low price (Vehicle to Grid Mode). Also, when the recharged EV is in idle mode, it can deliver power to the utility grid which is also termed as Vehicle to Grid Mode.

Therefore, this energy transferring mechanism will reduce the use of energy storage devices which are the major costlier parts of any charging station. Fig. 6 shows 3-D surface view obtained from MATLAB revealing variations of (a) charging cost with Renewable Power and EV power Demand (b) Charging cost with EV power demand and Time of Use.

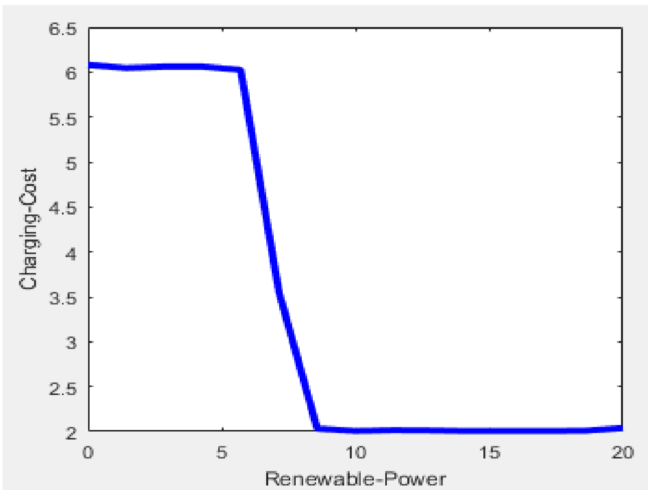


(a)

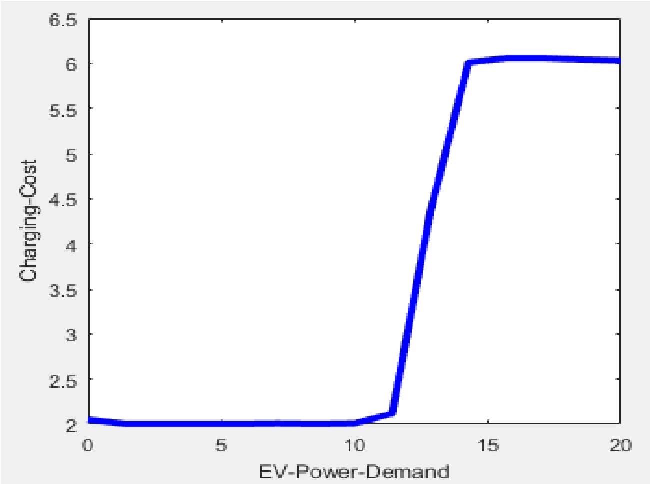


(b)

Fig. 6: (a) Surafce View of Renewable Power, EV power Demand and charging cost (b)Surafce View of EV power Demand, Time of use and Charging cost.



(a)



(b)

Fig. 7: Variation of Charging cost with (a) Renewable Power and (b) EV Power Demand

Fig. 7 shows the variations of EV charging cost with respect to Renewable power generation as well as for EV power demand. It is seen from the graph that when renewable power generation is sufficient the Charging cost will be minimum and operates in the Vehicle to grid mode if EVCS meets the present demand. Besides when EV power demand low, the charging cost also staying lower and with the gradual increase in the EV load, charging cost also increases. Fig. 8 shows the changes of energy transferring mode with renewable power generation in the EVCS. If EV demand exceeds the renewable power generation then the Grid to Vehicle Mode works with higher charging cost.

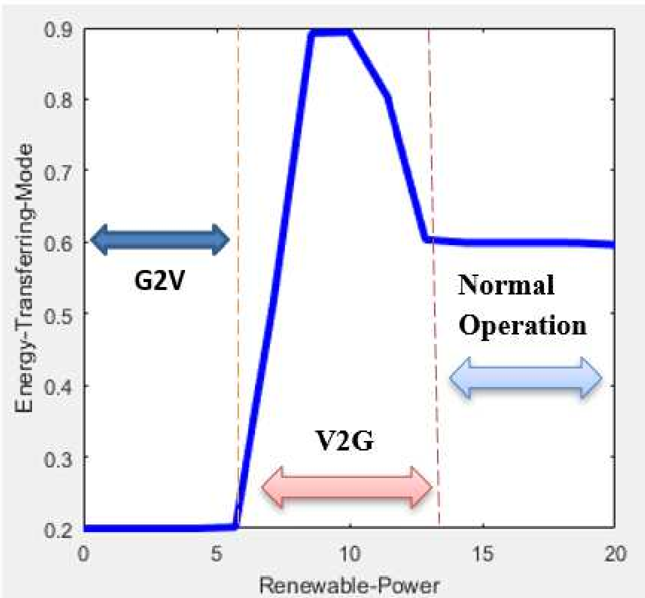


Fig. 8: Variation of Energy Transferring Mode with changes in Renewable power generation.

V. Conclusion

In this paper, the solar and biogas-based EV charging station is designed with energy transferring technology named V2G and G2V. As renewable power is cost-effective and eco-friendly, therefore the EV owners who recharge the batteries from renewable-based charging stations will be offered a lower price compared to the conventional charging station. However, in peak-hour, the charging cost is quite high to inspire the EV owner to recharge their batteries during the off-peak hour. The energy transferring scheme makes less use of storage devices which will be helpful for the reduction of charging cost and the maintenance of the battery management system. In the future, the cost analysis with environmental impacts of such hybrid renewable energy-based EVCS with energy transferring mechanism can be analyzed which will surely facilitate the sustainable development of Bangladesh.

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