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Duck Curve Problem Formulation and Solving Strategies by Utilizing PVr, PEVs, Load Shifting and ANFIS for Greening Bangladesh

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Abstract *– The installations of solar photovoltaics (PVs) in the distribution system, including rooftop photovoltaic (PVr) have been growing dramatically, which changes the shape of the daily demand profile in a way that makes it look like a duck. The duck curve is basically formed due to the huge unbalance of demand and high penetration of solar energy for a specific daytime period. This concern in the duck curve makes an outsized omission between the peak and off-peak and it leads to a recurrent ON and OFF of the thermal generators by escalating their start-up cost (SUC). As a solution, a considerable curtailment of solar energy from the existing system does not justify the installation cost of solar PV and its energy storage devices. This study is a futuristic case study for Bangladesh, where a high growth rate of Plug-in Electric Vehicles (PEVs) (20-25%) and rooftop solar PV (8%) for decarbonization may lead the load profile becoming not only a duck shape but also an inevitable blackout. To address these outgrowths, this study utilized the combined contribution of PEVs (energized by Lithium-ion battery), solar PVr, load shifting and Time of Use (ToU) based electricity pricing. Using PEVs may add up the system's total electrical load, but its optimal battery power management will give a smoother net load profile with better system stability. ToU based electricity pricing is a new electricity tariff standard for Bangladesh the new electricity tariff will encourage the consumer to be aware of using electricity properly, benefiting not only themselves but also the utility.*

Keywords *– duck curve, load shifting, plug-in electric vehicle (PEV), solar PV, ToU.*

1. INTRODUCTION

Nowadays, the world is heading towards renewable energy because of the limited reserve of fossil fuel and the fossil fuel-based electricity generation which harms the environment. Among all renewable energies the solar energy is the most popular as it is maintaining ever-decreasing technology and installation costs [1], [2]. In some countries, government incentives are ramping up this growth. Bangladesh is closely related to all above mentioned issues.

Bangladesh is a country of a hastiest booming economy globally with an average GDP growth rate of 6.5% since 2004. With the increased economic capability and modernization of technology, the use of electrical and electronic devices has increased drastically by the consumers. The increased load creates an extra burden on the electrical grid and that extra load is supposed to be impossible to be covered by the utility alone. So, there are several reasons behind the leaning toward non-dispatchable renewable energy for providing the extra power supply to the consumer level [3].

Firstly, natural gas (NG) is used for power generation as the primary energy source in Bangladesh. In addition, the current reserve of NG will support the country for the next 10-12 years [4]. Other resources are less to be described here. Bangladesh is sensitive to the world decarbonization agenda and is trying to minimize the use of fossil fuel because it has two limitations- i) the reserve limitations and ii) environmental limitations. Secondly, Bangladesh is following Sustainable Development Goals (SDGs) to have clean energy by utilizing non-dispatchable renewable energy sources and heading towards renewable energy. Solar energy has high potential for Bangladesh, but the installation of sufficient solar PV to have an extra power supply for consumers is not possible due to insufficient space. So, the installation of rooftop solar PV (PVr) is getting popular in Bangladesh. The first solar home system (SHS) was installed in Sylhet by a private organization in the mid of 1980s. Now, it has become very popular and has become the most effective SHS program in Bangladesh. All SHS units (4.5 million) are installed by the government's financial institution called Infrastructure Development Company Limited (IDCOL) [5]. The government stated that 10% (2000MW) of total generation should come from renewable energy sources by 2020. To fulfill this target we can get 20MW from rooftop solar system as most of the rooftop of residential or commercial infrastructure is partly or completely empty [6]. The government has mandated some rules to be followed by the consumers: for residential use of electricity, the consumer has to install 3% of solar PV of total household load on the rooftop and for industrial (light and fan) use, it has to be 7% of total installed load [7]. Moreover, there are some upcoming plans by which the consumers will be able to sell their extra generation

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of electricity to utility. This advantage will encourage the consumers to have more power generation by solar PV.

Undoubtedly, this is a positive change in the energy sector with environmental benefits, but this sudden increase in solar energy has some negative sides too, which should be considered before the problems get severe. Solar radiation is not the same throughout the day. More solar power production in rooftops of homes reduces the demand for dispatchable power of the utility sides. The generation of solar energy gets its peak at solar noontime and this generation necessitates on shutting down the other dispatchable energy sources [8]. The utilities observe that i) demand spikes: morning and evening, before declining at night, ii) problem of managing "Net Load", iii) forced ramp up of dispatchable plants for a morning peak, then dispatchable plants are shut down and are brought back all online (quickly) when the sunsets. There are some associated problems like i) the dispatchable generators having the qualifications of sudden ramping, stopping and starting are expensive, ii) in some cases such expenses are also not known to the utilities iii) sudden ramping, stopping and starting cause extra stress on power grid [9].

Moreover, the conventional generators could not support this high and sudden requirement of the power generation's ramping up. Consequently, a significant investment in the power grid is needed to meet this high peak demand. Ultimately, grid investment passes to the customers as electricity price/bill increases. Again, over current flow during peak-hours can adversely affect the transmission lines and reactive power control devices. An immense valley in the load curve also means less electricity utilization by the consumers from the utility [10].

In Ref. [11], some researchers of the National Renewable Energy Laboratory (NREL) investigated integrating a large scale of renewable energy into the electrical grid. They found a strange shape of load curve while integrating a large-scale solar power generation in the electrical grid. Later, it was named the, "duck curve" by the California Independent System Operator (CAISO). So, it is mainly familiar as the California duck curve, shown in Figure 1. We can say that Duck curve is nothing but a particular shape of the load curve, where the difference between valley and peak is very high [12]. This specific shape of the load curve is formed because of asynchronous between the excess generation of solar power and, at the same time, the least demand for electricity from consumers [13].

Along with the California duck curve, many more countries are suffering from duck curve issues. They are familiar as, 'French Duck Curve', 'German Duck Curve', 'Australian Duck Curve', 'American Samoa Duck Curve' [15]. As rooftop solar PV is getting popular and obligatory in Bangladesh, soon Bangladesh could see a 'Bangladeshi Duck Curve'. This paper will investigate a probabilistic duck curve formation and its probable solution by utilizing existing resources from Bangladesh's perspective.

There are many studies where researchers tried to show the influence of duck curve in the power system. The NREL showed a repairable negative impact of the over generation of solar power in the power system [16]. Some studies show how to avoid duck curve formation by the curtailment of solar energy from solar PV, but this curtailment does not justify the installation cost of solar PV in the system [17]. One study in [18] tried to solve the duck curve problem by utilizing pumped storage hydroelectricity and renewable energy. A study showed in [19], utilized PEVs with a distributed power management algorithm to flat the duck curve. In Ref. [20], it has been shown that shiftable loads can contribute to flattening load profiles. In Ref. [21], demand response and storage systems were utilized to solve the duck curve problems. Ref. [20] tried to solve the duck curve issues by increasing energy efficiency by avoiding RE. Some studies showed that ToU based electricity price and tariff provoking could motivate more consumers to utilize battery storage system at their own cost [23].

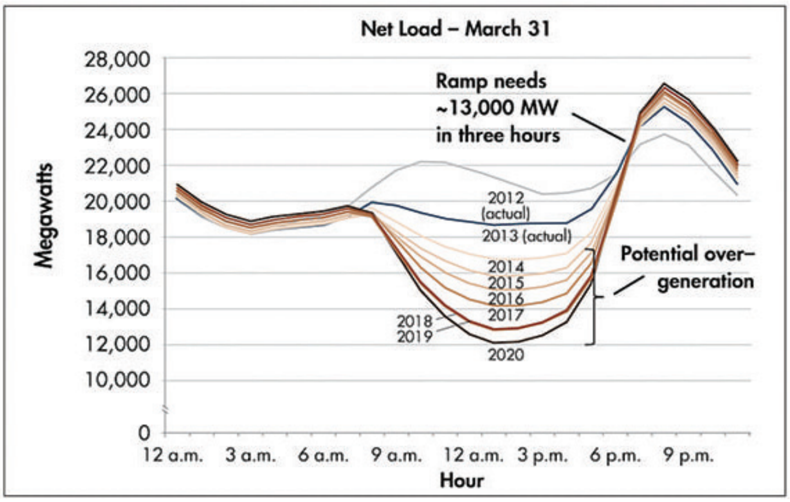

Fig. 1. The duck curve graphic California ISO and J. Lazar [14].

The duck curve has a deep valley which denotes less use of energy during that particular time. A storage system is necessary to utilize their energy. But energy storage system is expensive and not encouraged by the user. It is widely known that Plug In Electric Vehicle (PEVs) are getting better attention than any other transport mode due to its multi-purpose use in the smart grid [24]. It is an electrical load and can be used as an energy storage device [25]. To use PEV as a load and battery storage, it must have two-way energy transfer: from the grid to vehicle (G2V) and vehicle to grid (V2G). Recently, one study is carried out where it has been shown that simultaneous operation of both G2V and V2G can considerably flatten the load profile and contribute to grid stabilization [26].

Sometimes storing energy is also not sufficient for this solution. In this regard, demand response can be a useful add-on. ToU based electricity price can encourage the consumers to shift their load according to peak and off-peak hours [27].

So, flattening the Duck curve is an ultimate solution to all the above stated problems. There are some technical challenges those may be faced while flattening the Duck curve like i) how to flatten the Duck curve to reduce grid investment, ii) how to improve the load profile with PEVs capabilities, iii) how to interface load shifting, and iv) appropriate control strategy for the operation.

In this paper, to flatten the Duck curve both PEV and demand response were used. To use the PEV as a load and storage device, a flexible control strategy that helped PEV to perform V2G and G2V operation was used [26]. However, this study is a country-based operation, so the availability of PEV is a prime concern. In Bangladesh, PEV is getting popular due to legionary advantages like reducing the use of fossil fuel (imported), reducing GHG emissions by increasing the sustainability of the environment, cheaper in cost, least sound pollution, and lower government tax in purchasing PEV [28]. The automotive battery market size has grown three times in 2017 (estimated \$954 mn) compared to 2013 (\$358 mn) [29]. Even the Compound annual growth rate (CAGR) of the lithium-ion battery market is 7.2% more than the forecast period (the base year 2019 and study period 2018-2025) [30].

An artificial intelligence based neuro-fuzzy inference system is utilized for the management of battery power. In this case, ANFIS performs well because of its user interface and battery power management capability. Due to this paper's page limit, the advantages of using ANFIS over other controllers are not considered in this work. A ToU based electricity tariff is proposed to shrink the battery wages by shifting some shift-able loads from high peak time to less peak time.

This paper is arranged in the following sections: system description (solar integration and formation of duck curve, load shifting, modeling of battery,) is shown in section 2, section 3 shows battery power management of PEV, section 4 shows control strategy, section 5 shows simulation results and discussion, and the conclusion is shown in part 6.

2. SYSTEM DESCRIPTION

In this paper, two PEVs available at home were considered and used to flatten the Duck curve considerably. Charging and discharging were taking place in the car parking of the house. This study's main objective is to make the load power curve much flatter by ensuring the proper flexibility of connection of PEV with the grid by means of the appropriate use of controller (ANFIS) and use demand response effectively by means of ToU based tariff. Figure 2 shows the home, which is considered with standard loads available in Dhaka city. Converters were used for connecting DC loads.

When PEV was plugged-in, the battery got connected with the help of DC blocking filter, bi-directional DC to DC converter, bus for linking DC voltage, AC/DC converter and a R-L filter. The charging and discharging of the battery depend on the direction of the current. The battery's charging was indicated by -ve battery current and the discharging state was indicated by +ve battery current. The DC/DC converter was used as a buck-boost converter to boost any weak voltage to a certain level. The smoothening was done by L (inductive) filter. The AC/DC converter was used to convert the AC to DC and DC to AC according to battery and grid demand. The converter had multi-functions like- working as a rectifier while charging and inverter while discharging.

2.1 Integration of Solar in the Home System and Formation of the Duck Curve

In this study, a 3kW solar panel, which would effectively produce 2.9kW power during the solar noon (1000W/m^2 irradiance standard value and 25°C temperature), was considered. This 2.9kW solar power turns the load curve into a duck curve. This particular configuration of the solar panel is considered only for analysis purpose. The solar power generation from sunrise to sunset is shown in Figure 3.

The figure shows that sufficient solar production starts at 9h and declines producing solar power just after 15h. During that period, the produced solar energy after getting integrated into the system turned the load curve into an unusual shape. The new curves' peaks and valleys got a new shape which looked like a "Duck" that's why the new load curve was named as "DUCK CURVE". The duck curve is depicted in Figure 4. For the analysis purpose, all the waveforms were segregated into six periods.

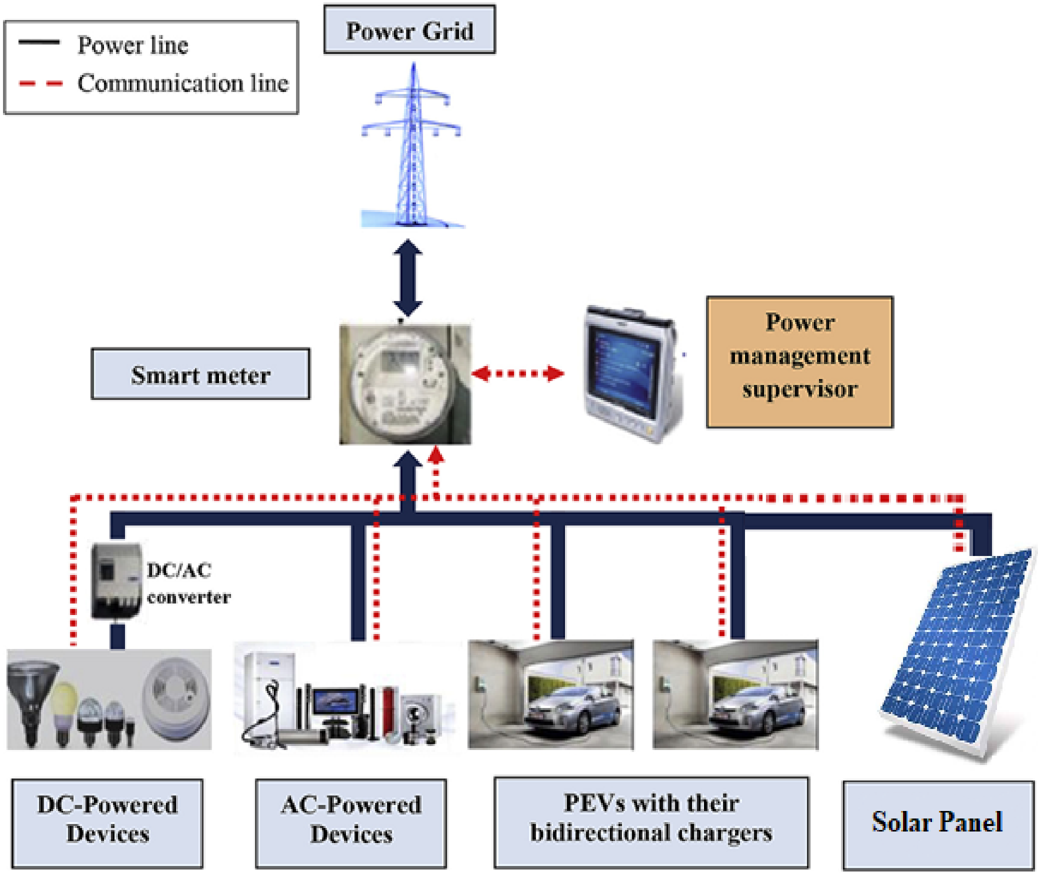

Fig. 2. Outline of home equipment.

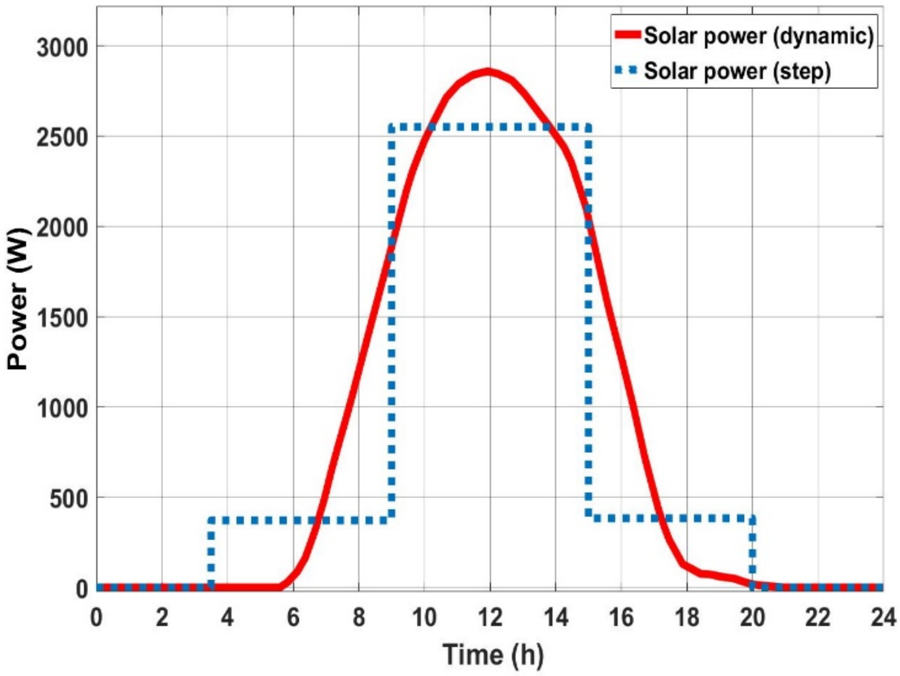

Fig. 3. Solar power generation from sunrise to sunset.

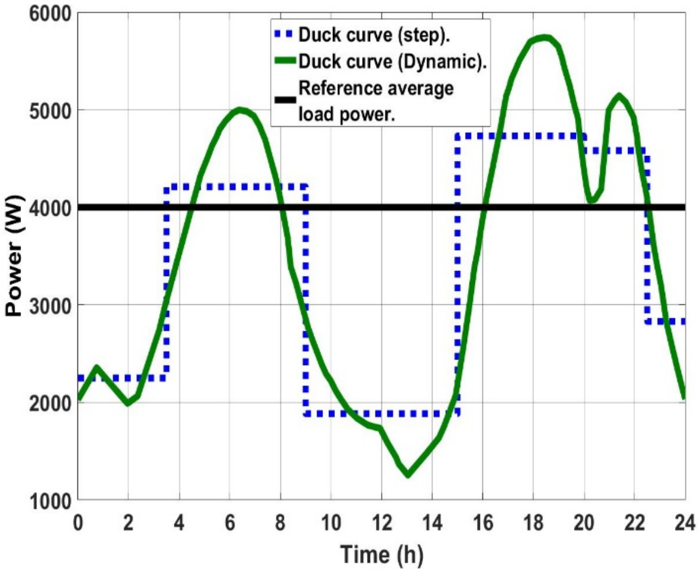

Fig. 4. Formation of duck curve by adding solar.

2.2 Load Shifting by Time of Use (ToU) based Tariff

ToU based tariff could play an important role in making the power system well balanced. The advantages of using ToU tariffs are that the utility can avoid constructing additional expensive power plants. The demand side is well managed, and consumers can lower their electricity bills as they are informed about the electricity price of different times of the day. In this regard, a smart meter was mandatory as it provides real time data of energy consumption to the utility as well as to the consumer.

Table 1. Exiting tariff for different consumption hour [31].

	Time of day	Energy rate (Tk./kWh)
Tariff Type	Flat rate (0h-24h)	8.00
Type-1	Off-peak hour (0h-17h)	7.20
Type-2	Peak hour (17h-24h)	10.00

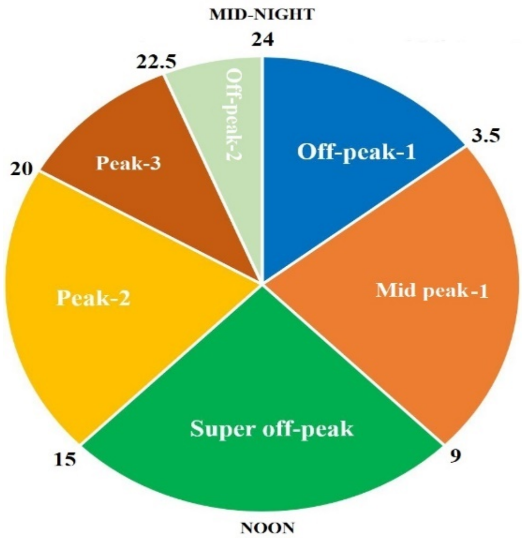

Fig. 5. Different load condition for 24 hours.

The updated electricity tariff provided by Dhaka Power Distribution Company Limited (DPDC) was collected [31]. For this study, Medium Voltage (MT) residential electricity tariff MT-1 was considered, which is shown in Table 1. The flat rate (type-1) is applicable for comparatively smaller load sized residents where the peak and off-peak rate is suitable for a relatively higher load size. But this existing tariff was not effective for flattening the probabilistic duck curve and need more segregation of the current tariff. For the dynamic pricing analysis, the duck curve (with and without PEV) was segregated into six periods. To attract the consumers for load shifting and at the same to facilitate the utility a ToU based electricity pricing was proposed, which is given in Table 2. Different load condition is shown in Figure 5.

Table 2. Proposed pricing for different consumption hour.

Time of day	Energy rate (Tk./kWh)
Off-peak hour-1 (0-3.5h)	5.00
Mid Peak hour-1 (3.5h-9h)	7.00
Super Off-peak hour (9h-15h)	3.00
Peak hour-2 (15h-20h)	10.00
Peak hour-3 (20h-22.5h)	10.00
Off-peak hour-2 (22.5h-24h)	5.00

Table 2 depicts the proposed electricity tariff along with the power used in a different time. Moreover, it shows that most energy surplus is taking place from 9h to 15h, so to attract consumers to use more power during this period, the price was considered as lowest. The reason behind choosing such a price was the consumer's unavailability and the wastage of most energy. So, offering as much as the lowest price during that period encouraged consumers to fulfill their maximum demand and utilize the surplus power. By using smart load management, some shift-able loads were shifted to that period. For this analysis, some available shift-able loads were considered, which are listed in Table 3.

Segregation of different peak and off-peak hours is depicted in Figure 5. In Figure 7 the negative sign indicates energy shifting from peak hours to off-peak hours and the positive sign indicates energy shifting from off-peak hours to peak hours.

After load shifting, the Duck curve in Figure 6 turned into the shape of Figure 8. The total electricity price of different periods is also shown in Figure 8.

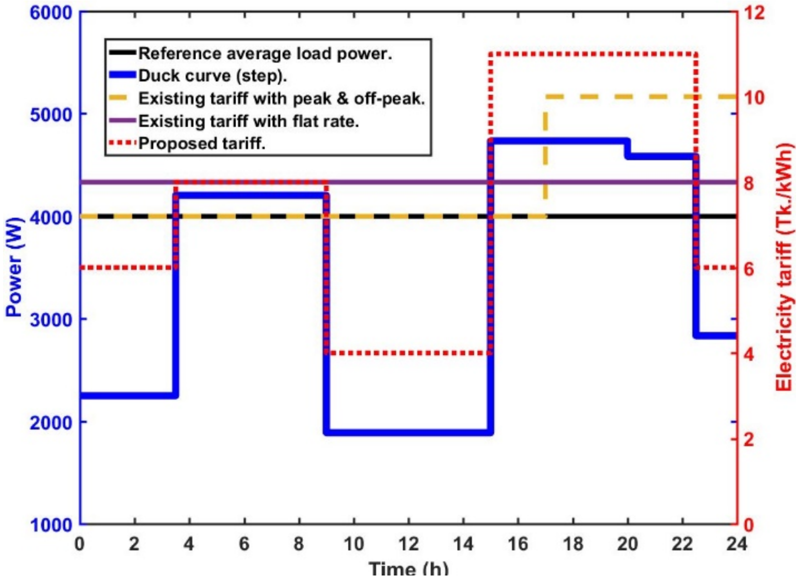

Fig. 6. Power and electricity tariff plot for different consumption hours.

Table 3. Some shift-able loads and their energy consumption.

	Shift able appliances	Power ratings (W)	Daily usages (h)	Energy Consumptions (Wh)
1.	Water heater	1800	1	1800
2.	Washing machine	600	1	600
3.	Electric iron machine	1000	0.5	500
4.	Air conditioner (2 units)	1500×2 =3000	3	9000
5.	Water pump	1100	1	1100
6.	Microwave oven	600	0.5	300
7.	Food blender	400	0.5	200
		Total energy consumption (Wh) =		13500

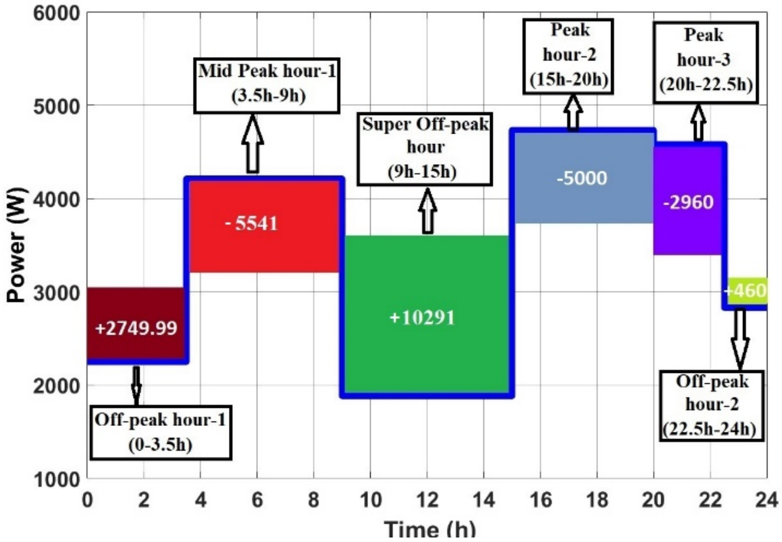

Fig. 7. Load-shifting (according to peak and off peak hours).

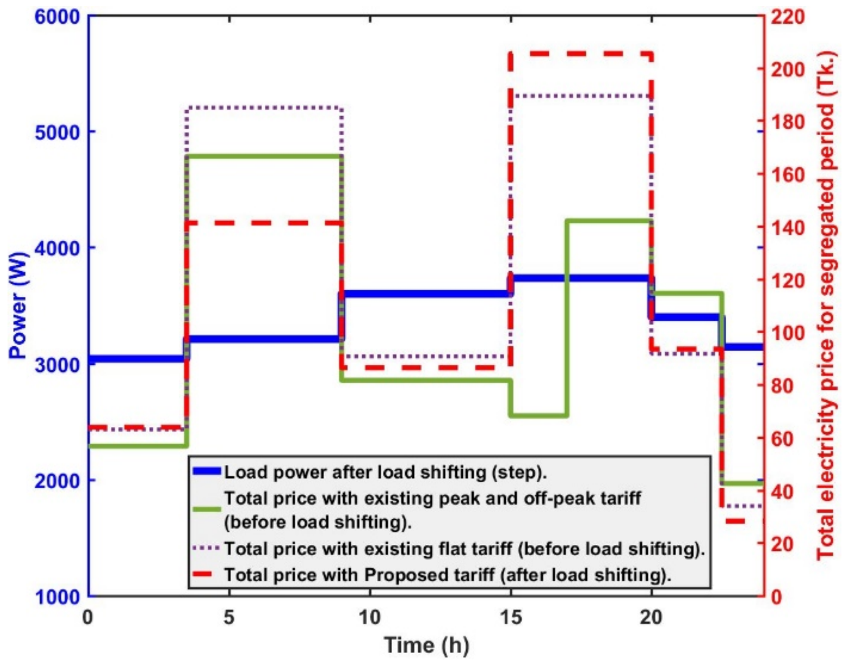

Fig. 8. New shape of load curve with total electricity price for each period.

2.3 Modeling of the battery

The battery used in the vehicle was Li-ion. In this paper a very classical model of the battery was used and all specifications are well described in [26]. One extra concern in this paper was to ensure better battery life by maintaining the battery SoC level to a certain percentage. Where State of Charge (SoC) is the level of charge of an electric battery relative to its capacity. The units of SoC of battery is measured as percentage (0% = empty; 100% = full). In this study, a fixed range of SOC percentage was considered to maintain battery health and avoid overcharging and deep discharging.

$$SoC_{min} \leq SoC \leq SoC_{max}$$

Where

$$SoC_{min} = 0.2 \text{ and } SoC_{max} = 0.8.$$

3. POWER MANAGEMENT OF PEV BATTERY

To perform the V2G and G2V operation an exact control strategy and bidirectional arrangement were necessary. In this study, a well-developed control strategy for PEV battery power management was utilized from [26]. The main difference between the [26] and this study was in terms of controller choice. The existing system in [26] was constructed with conventional PI controller where this study replaces this PI controller with a modern AI (artificial intelligent) based ANFIS controller. The whole system is redrawn with the ANFIS controller in PI controller replacement and shown in Figure 9. In this study, a brief description of the newly added parts was given.

Power production by each PEV was possible with the help of different power converters and power control of each PEV was ensured by controlling these converters.

Control of current: To have the reference battery current "$I_{bat\text{-}ref}$" from the battery charging/discharging an ANFIS controller was utilized. The -ve battery current represents the charging state while +ve battery current represents the discharging state. The following equation given the expression of the controller:

$$V_{m-bat} = V_{bat} - controller(I_{bat-ref} - I_{bat}) \quad (1)$$

Where, $V_{m\text{-}bat}$ is the modulated voltage of DC/DC converter, the battery voltage is V_{bat} and the battery current is I_{bat}.

Control of the converter: The main purpose of using DC/DC SMPS (switched-mode power supply) was to convert the battery voltage to a certain DC voltage level, which was suitable for inverter input. Otherwise, it was not possible to maintain a proper DC bus voltage. The duty ratio for DC/DC SMPS is given by the following equation:

$$m_{bat-ref} = \frac{V_{m-bat}}{V_{DC}} \quad (2)$$

Control of DC bus voltage: An ANFIS controller was used to control DC bus voltage by maintaining a proper "$I_{bat\text{-}ref}$". Then, nominal reference battery power $P_{bat-ref}$ was calculated for an adequate power exchange between the PEV and power grid. The equation of $P_{bat-ref}$ is given as follows:

$$P_{\text{bat}-\text{ref}} = P_{\text{DC}-\text{ref}} + P_D \quad (3)$$

Where, P_{DC-ref}=reference power of DC bus voltage
P_D=demand power.

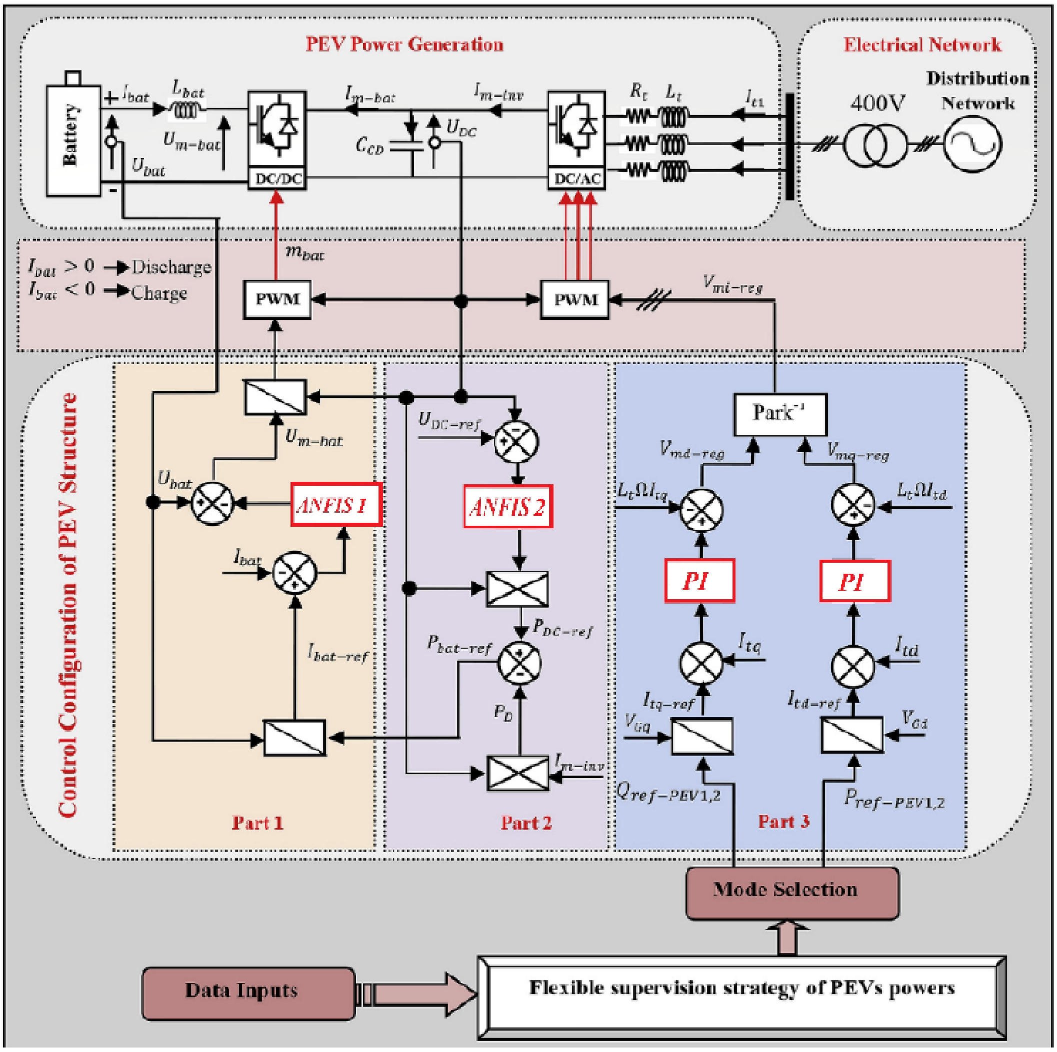

Fig. 9. Control design of each PEV structure for power production [26].

3.1 *Neuro-Fuzzy Hybrid Controller Design for Battery Power Management*

In terms of controller choice, ANFIS was better because it utilizes Sugeno, which gives better flexibility in the modification of MFs by means of data set. To design ANFIS, a toolbox named Fuzzy from MATLAB was utilized. The fuzzy toolbox has different features like- fuzzy inference system (FIS), MF (membership function) for input and output, rules view, rules editor and surface view.

In this study, two ANFIS (ANFIS1 and ANFIS2) controllers were designed: one for DC bus voltage control and another for battery current control. Two input variables were considered and regulated for better accuracy of the system like error and change in error. One output variable named ALC (Adapted Learner Content) was also controlled. The error was calculated by taking the difference between actual and reference value. Change in error is a ratio that was calculated from the difference and reference value.

A data set is required for ANFIS input, which was generated by the Fuzzy toolbox. Two input variables and seven (7) membership functions based fuzzy system was considered. To generate data for ANFIS1, one parameter was error in current, and another was change in error in the current. The following equation was utilized to calculate error:

$$V_{m-bat} = V_{bat} - controller\left(I_{bat-ref} - I_{bat}\right) \qquad (4)$$

Change in error in current was calculated by taking the ratio between error current and reference battery current. The following equation as utilized for estimating the change in error:

$$Change\ in\ error = \frac{\left(I_{bat-ref} - I_{bat}\right)}{\left(I_{bat-ref}\right)} \qquad (5)$$

To generate data for ANFIS2, one parameter was an error in bus voltage, and another was a change in error in bus voltage. The following equation was utilized to calculate error:

$$Error\ in\ bus\ voltage = V_{\mathrm{DC-ref}} - V_{DC} \qquad (6)$$

Change in bus voltage error was calculated by taking the ratio between error in bus voltage and reference bus voltage. The following equation was used for calculating the difference in error:

$$Change\ in\ error = \frac{(V_{\mathrm{DC-ref}} - V_{DC})}{(V_{\mathrm{DC-ref}})} \quad (7)$$

With the help of above mentioned Equations 4, 5, 6, and 7, two different data sets were generated. In the ANFIS toolbox the prepared data set was uploaded and after training the new FIS file was generated. The Figure 12 shows all the steps of training the data by the toolbox. The training error is shown in Figure 13 and ANFIS structure with input and output is shown in Figure 14. The objective of utilizing ANFIS was to adjust the voltage/current level to a particular value from any range of error value of voltage/current produced by a system's malfunction.

The training procedure began with the suitable training data set. 70% data from each data set was utilized for training purposes and the rest of 30% data was utilized for testing purpose. The training data set contained enough reference values for better output. The input data set was in the matrix form. The final membership function with training data was formed at the end of the training process (trn-fismat). The trained data set was justified against the testing data set to check the proposed system's rationality.

The prototyped model was initiated with default membership function (7*7), where "Triangular-shaped (trimf)" membership function was used. The produced FIS system containing 49 rules was produced by genfis1 algorithm. To establish the relationship between the input and output and to compensate error, the whole training procedure was gone through the neural network.

The equation of root means square error (RMSE) was utilized for error investigation and the equation is shown below:

$$RMSE = \sqrt{\frac{1}{n}\sum_{k=1}^{n}(z_k - \hat{z}_k)^2} \quad (8)$$

The equation of Mean Average Error (MAE) is as follows:

$$MAE = \frac{1}{n}\sum_{k=1}^{n} |\ z_k - \hat{z}_k\ | \,, \quad (9)$$

Where, the total forecasted number is n, $\hat{z}_k$ is the forecasted time series, and z_k is the main series

The overfitting issue was solved by setting an appropriate training epoch.

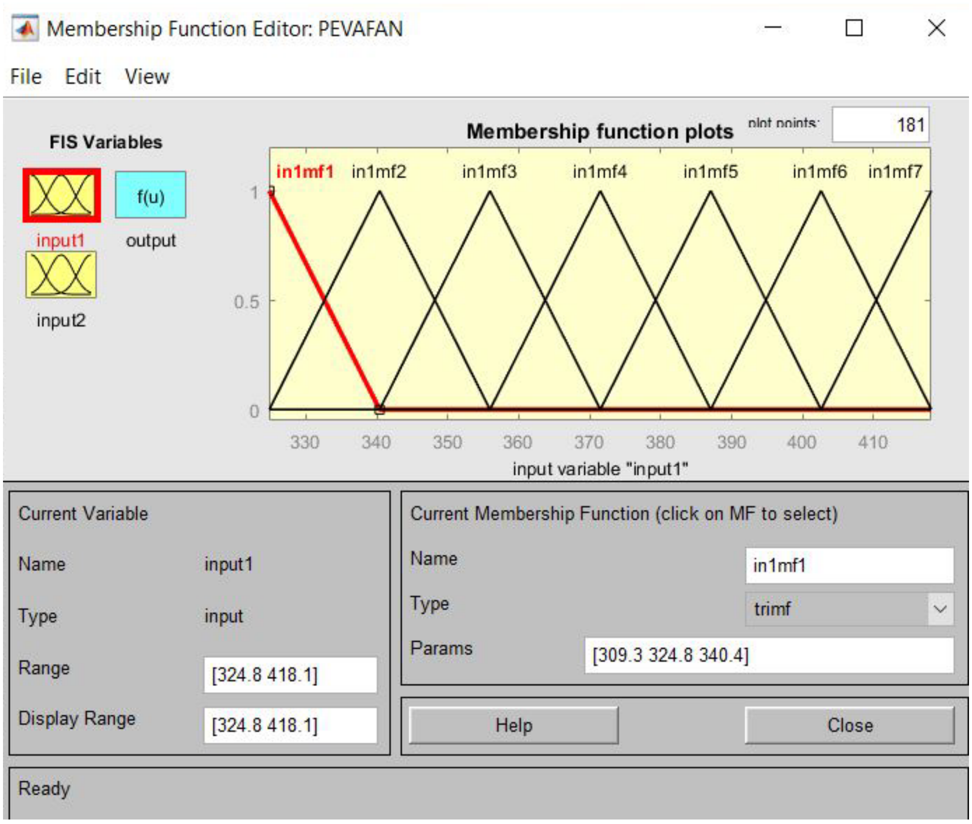

Fig. 10. Input membership function 1.

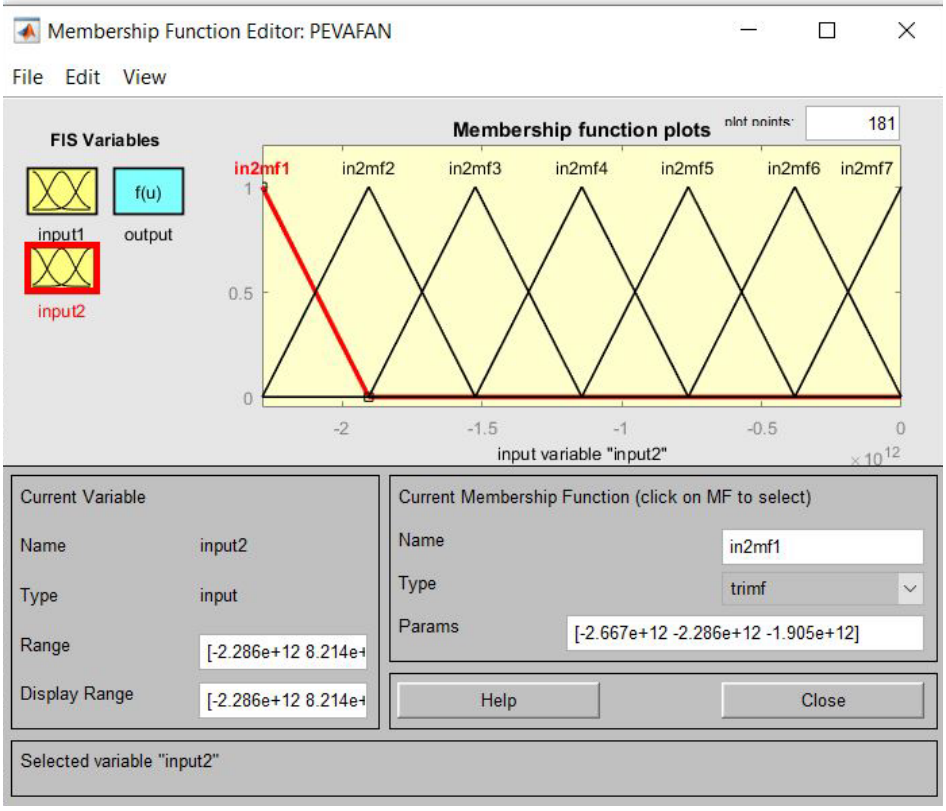

Fig. 11. Input membership function 2.

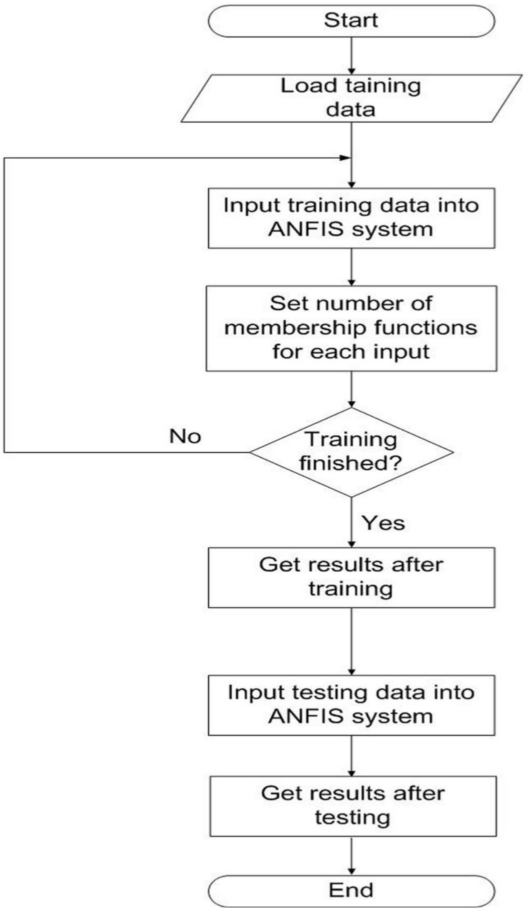

Fig. 12. Different steps of ANFIS training for battery charging [32].

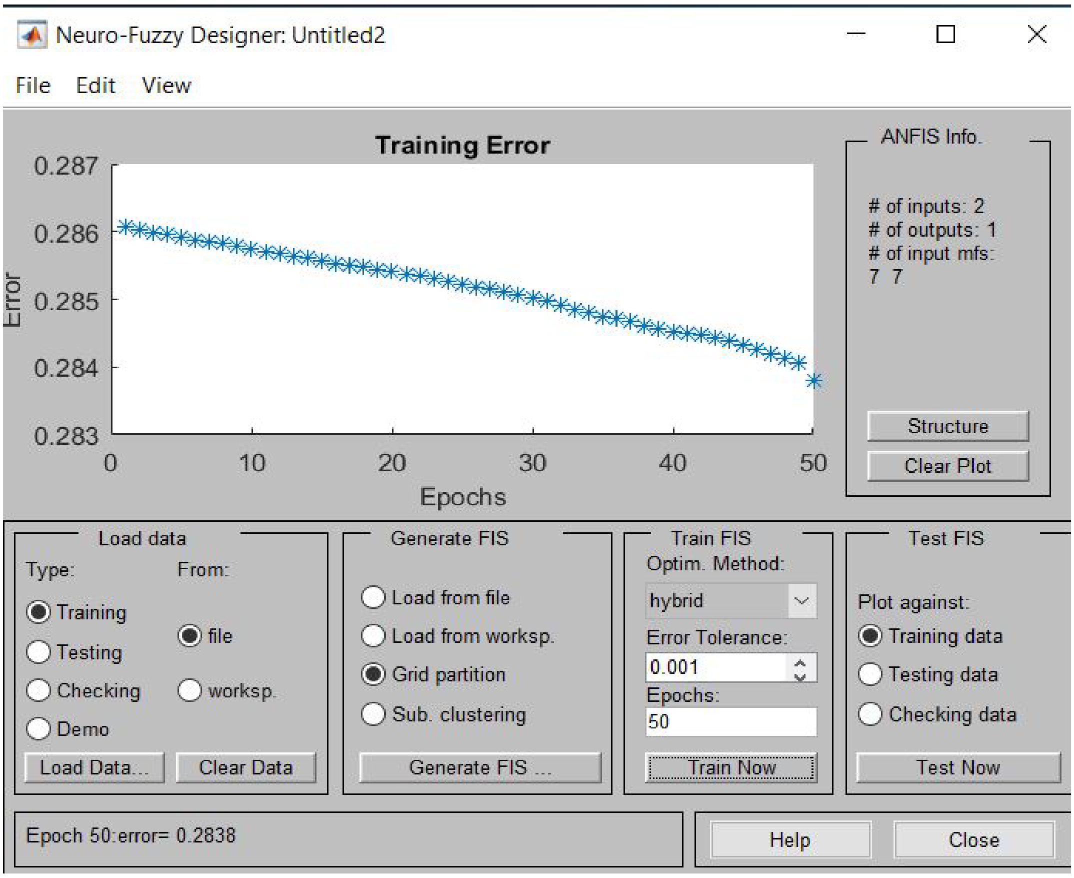

Fig. 13. Training error of ANFIS.

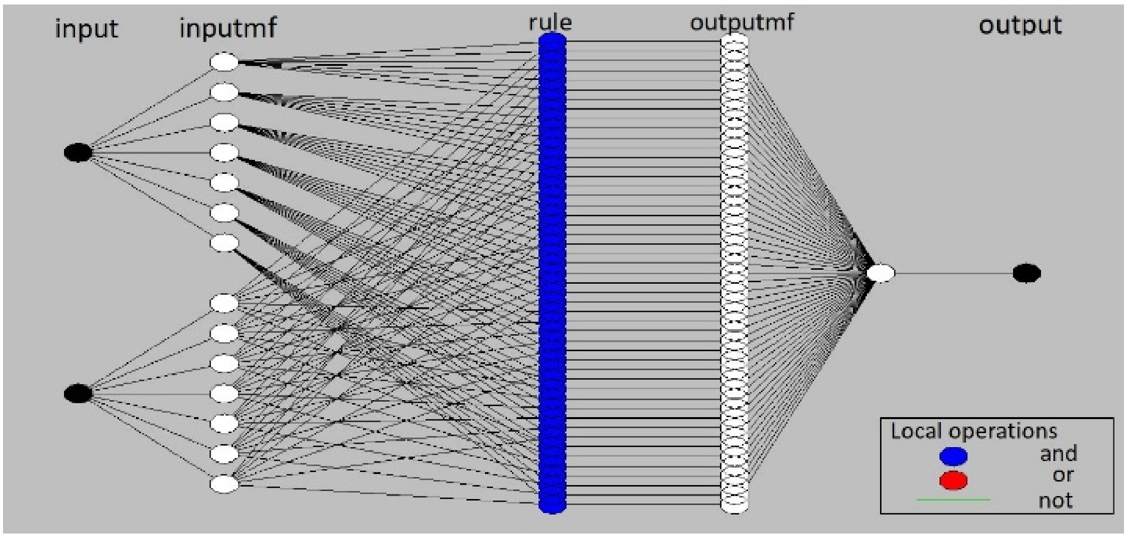

Fig. 14. ANFIS structure showing input(s) and output.

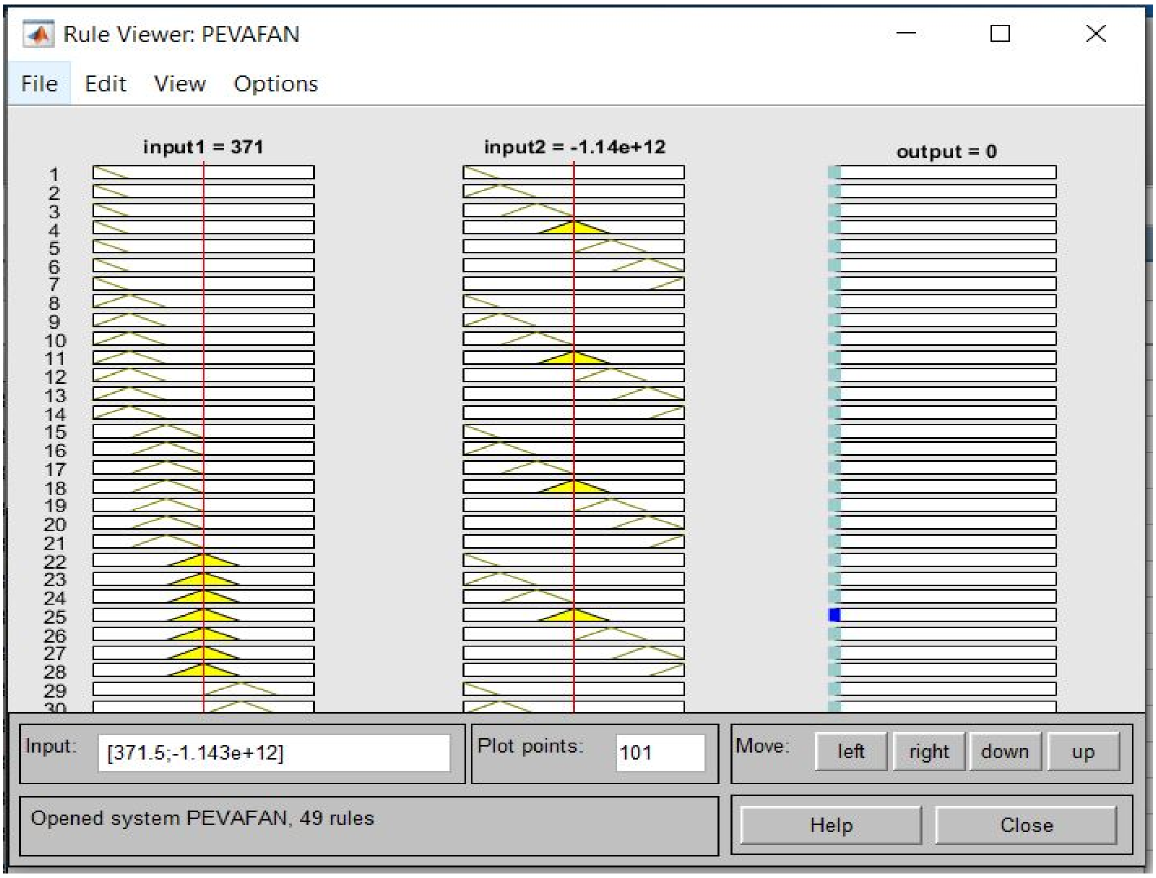

Fig. 15. Rule view of ANFIS.

4. CONTROL STRATEGY

To perform an optimal power flow between the PEV and grid, a control algorithm shown in Figure 16 was necessary. In this work, a very effective control strategy was inherited from [26]. The whole control strategy is well described in [26]. The following equation calculated in the controlled power flow that should be absorbed/injected to the grid from PEV:

$$P_{diff}=P_L-P_R \quad (10)$$

Where, P_{diff}=absorbed or injected power,
P_L=load power,
P_R=reference load power of considered home.

The following equation given the reference power:

$$P_R = T\sum_{t=1}^{T}(P_L + P_{PEV1} + P_{PEV2}) \quad (11)$$

Where, T is the connection time of each PEV.

5. SIMULATION RESULTS AND DISCUSSION

To validate the effectiveness of proposed system, a simulation of Duck curve smoothening was carried out. In this study two PEVs were considered. PEV1 had a battery size of 14kWh and for PEV2, it was 11kWh. The PEVs SOC limit was 0.2 to 0.8. So, that the PEV could have better battery life for a longer period than as usual.

Figure 17 shows that PEV1 was connected to the grid during the following periods [0h, 7.30h], [12h, 15h], and [19h, 24h], but it was not connected to the grid during these periods [7.30h, 12h] and [15h, 19h]. In the same figure, PEV2 was connected to the grid during these periods [0h, 11h], [12.30h, 15h], [17h, 21h], [21.30h, 24h] but not connected during these periods [11h, 12.30h], [15h, 17h], [21h, 21.30h]. During their connected period they either could perform G2V or V2G operation according to their demand/capability and the proposed algorithm justified this operation. When they were not connected to the grid in those periods, they were used for traveling.

The total number of PEVs was counted from their connection status at home parking.

"$N=CS_{PEV1} + CS_{PEV2}$"

The working mode 4.2 was available for the time intervals [0 h, 4 h], [6 h, 7:30 h], [12:30 h, 14:30 h], [20 h, 21 h] and [22 h, 24 h]. In mode 4.2, both PEV1 and PEV2 were in the charging phase. Mode 4.1 was activated when discharging was necessary (Figure 14).

Mode 7.2 was activated in the time interval [4 h, 5:15 h] where mode 7.2 was activated in the time interval [18 h, 18:40 h]. The total power exchange was provided by PEV2 that might have "SoC_{min}" or "SoC_{max}" [Figure 14].

During the periods [5:15 h, 6 h] and [18:40 h, 20 h], mode 5.2 was activated and SoC of each PEV was SoC_{max}. Again, in the mode 5.1 both PEVs had SoC_{min}. So, no power exchange was possible in mode 5 [Figure 14].

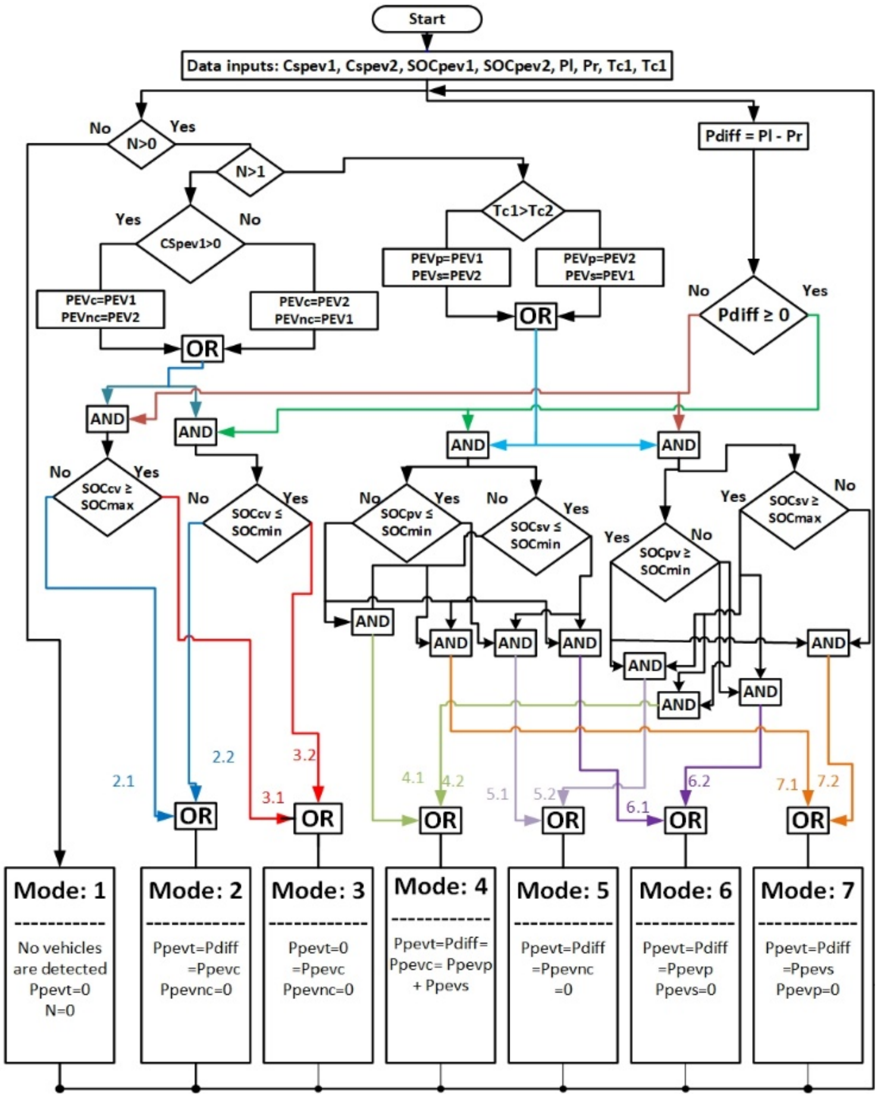

Fig. 16. Adaptive supervision system of PEVs powers [26].

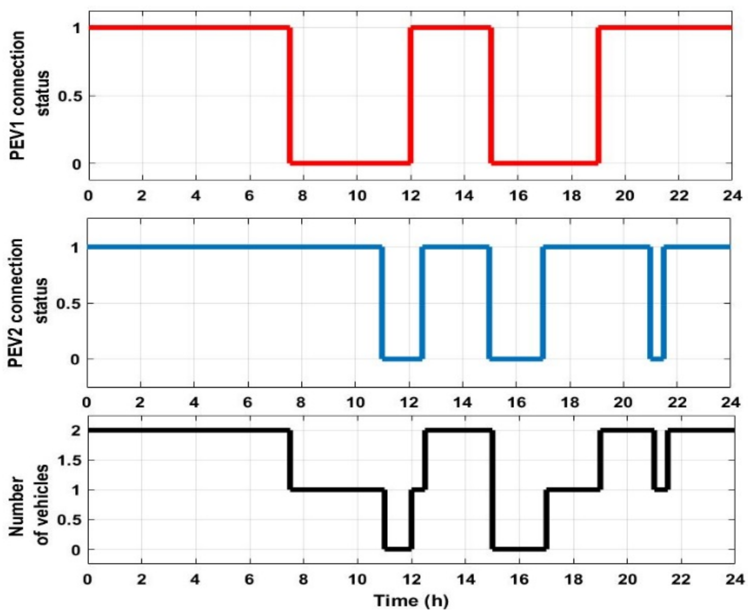

Fig. 17. Various connection states for each PEV.

Mode 2.2 was activated in the intervals [7:30 h, 8:30 h] and [21 h, 21:30 h], where at first interval SoC of PEV2 was at its maximum and at second interval PEV1 was kept charging. Mode 2.1 worked during the time intervals [8:30 h, 10 h] and [12 h, 12:30 h]. In the modes 2.1 and 2.2, both PEVs performed G2V operation. [Figure 14].

Mode 3.1 and 3.2 were detected during the intervals [10, 11 h] and [17, 18 h], respectively. In the first interval, PEV2 was detected with "SoC_{max}" and in the second interval with "SoC_{min}". [Figure 14].

In the time [11, 12 h], and [15, 17 h], mode 1 was detected and no PEV was connected to the grid.

Mode 6.2 worked at [14:30 h, 15 h] and mode 6.1 worked at [21:30 h, 22 h]. In these modes, power exchange was contributed by the priority vehicle (PEV2). [Figure 14].

The comparison of different load power curves is shown in Figure 19. The load curve (pink dotted line) that was converted to the Duck curve (green line) was considerably flattened (red dotted line) by proper load shifting (blue line) and implementing appropriate control strategy for PEV. But some certain periods of duck curve (blue line) could not be flattened due to the unavailability of PEVs.

5.1 Load Factor

Load factor (average-load/peak-load) was a proper way to compare this study's outcome with the work [26]. The average load value was 4985W and peak load value was 5833W. So, the load factor of the work [26] was 4985/5833=0.85. The average load value was 4000W and the peak load value was 3960W. So, the load factor of this study was 3960/4000=0.99. A higher load factor is better because of the higher utilization of resources. Different value of load data and load factor are shown in Table 4.

5.2 Cost savings by a consumer

By controlled charging of PEVs and load shifting, the consumer was benefitted financially. Table 5 shows the cost of controlled/uncontrolled charging of PEV and load shifting on a daily and annual basis. This table it is clearly shows that by controlled charging of PEV and proper load shifting, a single house could save 22728.23Tk. per annum compared to the existing flat tariff and 29442.07Tk. per annum compared to existing peak and off-peak tariff. So, these cost savings encouraged the consumers to flatten the Duck (load) curve.

Table 4. Different values for load factor.

Parameters	Average load (W)	Peak load (W)	Load factor	Load factor improved (%)
[26]	4985	5833	0.85	16.47
Proposed method	3960	4000	0.99	

Table 5. Cost comparison for the different tariffs.

Parameters (Electricity cost)	Daily cost (Tk.)	Annual cost (Tk.)	Total cost savings per annum (Tk.)
Part 1. Uncontrolled charging of PEV before load shifting with existing flat tariff	653.84	238650.02	22728.23 (comparing part 3 with part 1)
Part 2. Uncontrolled charging of PEV before load shifting with the existing peak and off-peak tariff	672.23	245363.86	29442.07 (comparing part 3 with part 2)
Part 3. Controlled charging of PEV after load shifting with proposed tariff	619.51	215921.79	

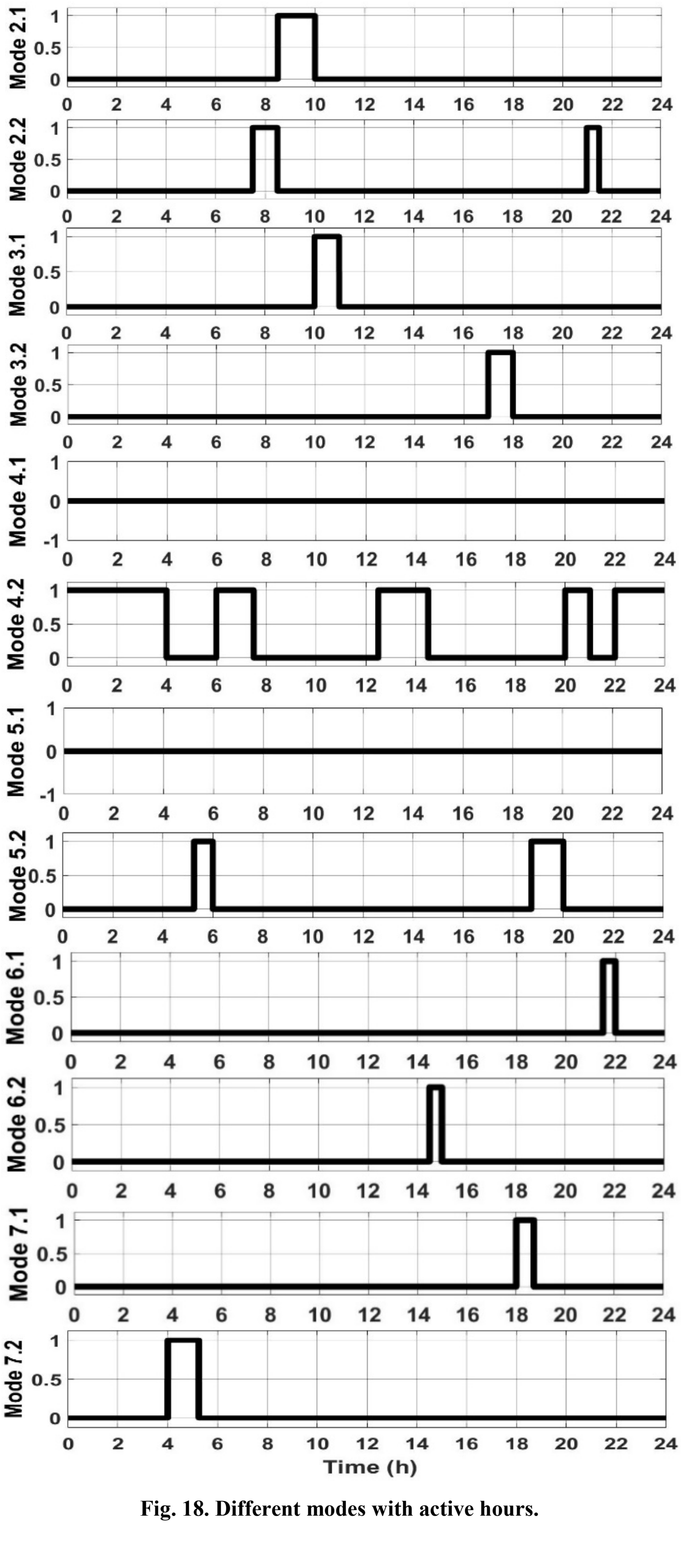

Fig. 18. Different modes with active hours.

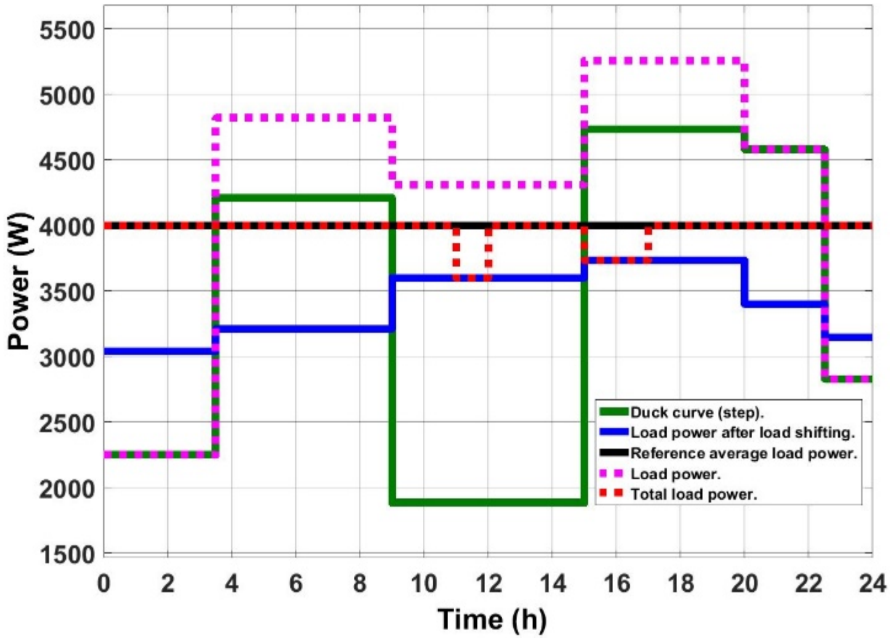

Fig. 19. Comparison of load power curves.

Table 6. Different results of THD using different controller.

Parameter's Name	THD (%) at T=10	THD Improvement (%)	THD (%) at T=15	THD Improvement (%)
PI controller [26]	27.81	18.27	28.67	26.75
ANFIS controller	22.73		21.00	

5.3 Total Harmonic Distortion (THD)

In this study, the ANFIS controller was used instead of the conventional PI controller and found that total harmonic distortion (THD) was improved too. THD of this study was a byproduct parameter.

Table 6 above informs the calculation of THD for both periods and it was clearly seen that harmonics were much improved by replacing PI controller with the ANFIS controller.

6. CONCLUSION

In this study, we anticipate a likely technical problem in Bangladesh with solar rooftop penetration. It can be shown by shape of the load curve assuming the shape of a duck curve. The solution methods both in supply side and in demand side were discussed in the perspective of Dhaka city (capital of Bangladesh). A proper load shifting and a flexible control strategy of two PEVs were used as example to sort out the duck curve problem. Proper load shifting was possible by considering ToU based electricity pricing. Segregation of load power into six periods of time within 24 hours gave a better opportunity to shift the necessary shift-able loads from peak hours to off-peak hours. This considerably flatten the load profile. However, to utilize the energy and resources completely, an energy storing device was important. In this regard, existing PEVs used by the consumers were considered as a good storing device. So, in case of charging and discharging the PEVs, a flexible control strategy with seven operating modes was investigated in this study. This control strategy ensured the bi-directional flow of power between the PEVs and the grid, and the power management was measured by ANFIS controller. The regulated charging of PEVs and required power injection into the grid were made possible by both control strategy and ANFIS controller to avoid the huge energy consumptions during the peak hours. Different simulation results justified the whole procedure. Finally, the combination of proper load shifting with ToU based tariff and regulated charging of PEVs considerably flatten the Duck curve as expected.

ACKNOWLEDGEMENT

I would like to express my deep gratitude to Bangabandhu Chair Professor at AIT, Professor Joyashree Roy whose input helped me to complete the financial assessment part of the article. She also gave me the overall idea about writing the paper and thankful to her for frequent discussion time as committee member during my master's thesis work.

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