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Flexible Cost Factor for Tariff Modeling Using Fuzzy Logic Approach in Wind Energy Applications

V. Sharmila Deve, K. Geetha and K. Keerthivasan
Department of Electrical and Electronics Engineering, Karpagam Institute of Technology, Tamil Nadu, India

Abstract: Depletion of fossil fuels and their impact on the environment had forced the central power authorities now a days to focus on renewable energy sources. Most of the countries practice 'Feed in Tariff' mechanism in the process of purchasing wind energy from Wind Power producers. The drawback of this Tariff method is the fixed rate per unit irrespective of the power demand and wind speed. To overcome this drawback and to promote the usage of wind energy, in this research, an optimal 'Flexible Feed in Tariff' model for wind energy purchase has been developed. This tariff is designed based on the variable nature of wind speed and daily power demand using fuzzy logic. This 'Flexible Feed in Tariff' will benefit both Central Authority and Wind Power Producers. Finally, the proposed tariff model is compared with current tariff, Independent Power producer Tariff and Private parties Tariff of Tamilnadu state of India, which depicts that the proposed tariff model is better than other compared tariff mechanism.

Key words: Flexible feed in tariff, fuzzy logic, power demand, wind energy, wind velocity

INTRODUCTION

Though fossil fuels are the primary source of electric power generation, they lead to Global warming (Dominguez *et al*., 2015; Mathews, 2007). Fast depletion of fossil fuel, increased cost of fuel excavation and gradual rise in global temperature have forced the energy policy makers to focus on renewable energy sources especially wind energy (Xie *et al*., 2013; Khare *et al*., 2013).

India has an installed capacity of 225.79 GW as on November 2013. In that 12.32% of electricity is generated from renewable energy sources, of which around 70% contribution comes from wind energy. In India, wind mills are owned by both central authority and private parties. Central authority purchase power from private parties based on two methods, namely feed in tariff and renewable energy certificate (Sharma *et al*., 2012; Singh *et al*., 2009). Feed in tariff is a fixed tariff for every kilowatt hour of electricity fed to the grid and it is an effective tariff mechanism in promoting the development of renewable energy source (Zhao *et al*., 2013). This tariff may be suitable to a predictable nature of source. But, in wind energy system, wind speed is of highly variable nature and because of this the current fixed tariff mechanism is not economically viable.

In power market, uncertain nature of wind is considered by the market operators as penalty cost and online reserve cost (Hetzer *et al*., 2008). But, these costs are not economically suitable in India. Wind input power depends on wind velocity. Even at low wind velocity, wind energy supports critical power demand. Therefore by considering the variable nature of wind velocity and power demand authors introduce 'Flexible cost factor' using fuzzy logic. This factor decides the tariff named 'Flexible Feed in Tariff'.

The proposed tariff mechanism designed will result in a tariff that is less than that of Independent power producer and private parties and higher than current Fixed Feed in Tariff. Thus it is beneficial to the Wind power producers (WPP) and Central authority of Power.

Current scenario of wind power in india: In the year of 2000 the installed capacity of wind power was 220MW, and now by the end of November 2013, wind power installations in India reached around 20,000 MW. The fundamental reason for this rate of growth is the three key incentives offered by the central government, namely accelerated depreciation, generation based incentive and the renewable energy certificate mechanism (Khare *et al*., 2013).

Corresponding Author: V. Sharmila Deve, Department of Electrical and Electronics Engineering, Karpagam Institute of Technology, Tamil Nadu, India

In 2011, the Centre for Wind Energy Technology (CWET) of India reassessed India's wind power potential as 49,130 MW at 50 meters height at 2% of land availability (Indian Wind Energy Association, 2012). The south western parts of tamilnadu, andhra pradesh, karnataka, maharashtra, gujarat and rajasthan are some of the major states of India where wind power generation is in considerable amount (Rao and Kishore, 2009). From May onwards, wind power generation increases and helps to meet the power demand of the corresponding states of India. During monsoon periods (July-eptember) the maximum power generation through wind energy is achieved. Power generation through wind energy is less during the rest of the periods. Figure 1 shows the wind velocity of different bays of Tamilnadu state and the average wind energy consumption in Million Units (where 1 Unit = 1KWh) during the year 2012. During this period wind energy comes to the rescue of states that experience critical power deficit and enhances the southern region grid frequency.

Commercial wind power generation in India was started in the year of 1986. Many of the low capacity older turbines were positioned at some of the best sites. These turbines need to be replaced with more efficient, larger capacity machines to generate more electricity from the same site. India's current replacing wind turbine potential is approximately 2760 MW. However, due to lack of policy guidelines and less incentives provided, there is a big pull down in the replacements of old wind turbines.

Current methodology to determine feed in tariff for wind power: At present, feed in tariff mechanism is mostly practiced in India though REC mechanism has also been in practice. Hence, in this study, authors have chosen feed in tariff mechanism as the base to build the flexible feed in tariff. In this research work case study is done for Tamilnadu state of India. So, the authors considered the feed in tariff mode of Tamilnadu state for designing the flexible feed in tariff.

The components of current feed in tariff for wind energy specified by Henriksen (2013) are Capital cost, Capital Utilization Factor (CUF), Debt: equity ratio, term of the loan, interest rate, returns on equity, life of plant and machinery, depreciation of plant and machinery, operation and maintenance expenditures. Components involved such as the electrical and mechanical components, lubricants and machine performance decides the life of the plant. CUF is the ratio of total amount of wind energy of wind turbine produced and the amount of wind energy, the wind turbine would have produced at its full capacity during a specified period of time. CUF depends on wind power density, air density, mechanical efficiency and age of the machine, height of the hub and length of the blades. The capital cost for wind energy project shall include wind turbine, generator including its auxiliaries, land cost, site development charges and other civil work charges, transportation charges, evacuation cost up to inter-connection point and financing charges. Table 1 shows the values of the components of tariff of wind energy set by tamilnadu electricity regulatory commission. Calculation of feed in tariff based on the components and its values is shown in Appendix A.

MATERIALS AND METHODS

Inspiration to develop the proposed methodology: The region which experiences the heaviest energy shortage in India is the southern grid region, especially the states of karnataka and tamilnadu. In the year 2012, power deficit was more in India and is shown in Table 2. This energy shortage was met by planned load shedding and purchase of power from private parties at a very high cost, which was a big burden for the people of these states. Private parties here refers to conventional power producers who generate power from fossil fuels like coal, gas, diesel etc. and sell it to the electricity board on long term contract basis. Obviously to get benefitted more, they have fixed high cost per kWh for their power than its production cost. To meet the power deficit,

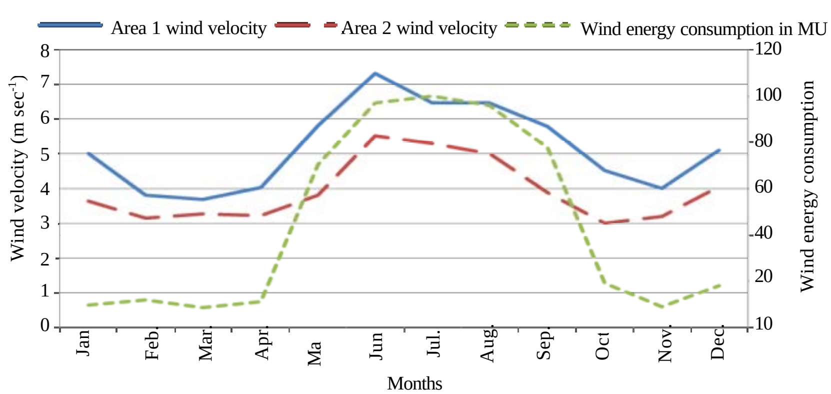

Fig. 1: Wind velocity of different areas and average wind energy consumption of Tamil Nadu in the year 2012

Table 1: Components and values of the tariff

Parameters	Values
Capacity utilization factor	27.15%
De-rating factor	1% for every year after ten years
Life of the plant	20 Years
Capital investment	Rs. 5.75 Crores
Debt : Equity ratio	70:30
Interest on loan	12.25%
Loan repayment period	10 years with 1 year moratorium period
Return on equity	19.85% Pre-Tax
O&M Charges for machinery on 85% of capital investment	1.10% with escalation of 5% from 2nd year
O&M Charges for civil works on 15% of capital investment	0.22% with escalation of 5% from 2nd year
Insurance charges	Clubbed with O&M charges
Depreciation on 85% of capital investment	4.5%
Residual value	10%

Table 2: Power deficit in india

Northern region	Western region	Southern region	Eastern region	North eastern region
-9.2%	-3.3%	-15.5%	-4.6%	-7.3%

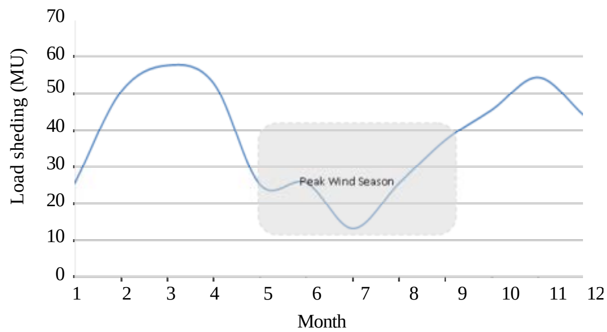

Fig. 2: Load shedding at tamilnadu during the year 2012

authorities of electricity board were forced to purchase power from such private parties. In this scenario, if power is purchased from private parties at a very high cost, it results in hike in the price of every product purchased and affects the Gross Domestic Product (GDP) of the country.

Figure 2 shows load shedding data of tamilnadu in the year 2012. It reveals the power deficit of the state. Normally from April to September, power shortage is comparatively low due to wind power generation. This Figure shows the important role played by wind energy in reducing the load shedding. Load shedding process may further be reduced during low wind seasons too by installing more wind power plants.

If the installed wind capacity is increased, shortage of power could be compensated using wind energy throughout the year. India has abundant wind energy potential. Since, there is no attractive incentive for wind power developers, it is not utilized fully. To encourage the WPP, India needs an integrated, clear and unique tariff model. To ensure power supply to the consumers ever by promoting the WPP and reduce the usage of fossil fuels, this proposed flexible feed in tariff model would be an ideal choice.

Proposed methodology: The power input to the wind turbine is dependent on the speed of the wind. As the maximum power input of the wind turbine is proportional to the cube of the wind speed, small variations in the wind velocity make a big difference in the input power as given in the below equation:

$$P_{wind} = 0.5pAV^3 \quad (1)$$

Where, p is air density, A is area of blades and V is the velocity of upstream wind of the wind turbine. When calculating the wind input power, it is important to take into account not only the wind velocity in that region but also the wind speed frequency distribution. Though output electric power from wind turbine depends on the efficiency of that turbine, basic factors that influences are wind velocity and wind distribution of that region. In India, based on historical data of wind speed frequency distribution, it is found that prominent wind potential states are andhra pradesh, gujarat, karnataka, Maharashtra, Rajasthan and Tamil Nadu.

Figure 1 shows the wind velocity of different bays of Tamilnadu state of India and the average wind energy consumption during the year 2012. It depicts that during peak wind season; generation of wind energy is more and compensates the power deficit. Hence, wind velocity is also included as a parameter in tariff calculation of wind power. Critical power demand is compensated by wind power as explained in the previous section. Hence, in the present research, the flexible feed in tariff model is developed in proportion to the wind velocity and power demand.

In the Flexible Feed in Tariff, WPP would supply power during off seasonal period of wind at an increased tariff. At the same time this tariff is lesser than other forms (IPP, purchase from private parties) of power tariff.

Current tariff of wind power is fixed feed in tariff which when added to the flexible cost factor becomes flexible feed in tariff as shown in Eq. 2.The flexible cost factor is a factor that takes into account the wind velocity of the area and the power demand of that state.

$$W_{i,pi,dt} = W_{i,Pi,ct} + \delta W_{i,Pi,ct} \quad (2)$$

$$TW_{Pi,dt} = \sum W_{i,Pi,dt} \quad (3)$$

where:

P_i = The power generated by ith wind turbine
$W_{i,Pi,dt}$ = The flexible feed in tariff of wind power of ith wind turbine
$W_{i,Pi,ct}$ = The current feed in tariff of wind power of i^{th} wind turbine
δ = Flexible cost factor
$TW_{Pi,dt}$ = The total wind power cost

Fuzzy logic model of flexible cost factor: Both, power demand and wind velocity exhibit non-linear characteristics due to their uncertainty. They should therefore be presented as the fuzzy quantities.

Three variables are considered as fuzzy variables. They are wind velocity, power demand and flexible cost factor. For the design of flexible cost factor, fuzzy logic model implementation is shown in Fig. 3. The fuzzy logic model adopted in this work comprises of two functional blocks. The first block is database block, it contains the membership functions of the input fuzzy sets used in the fuzzy rules and the next one is knowledge base block, to define the number of fuzzy, if-then rules. Based on the knowledge base, the database is the fuzzy reasoning unit, to perform the inference operations on the rules. First fuzzification operation is done with the crisp input of wind velocity and power demand, in which the crisp input variable is compared with the membership functions on the premise part to obtain the membership values of each linguistic fuzzy set. These input membership values from the premise part are combined through a 'and' connection operator to get firing strength (weight) of each rule in order to generate a qualified consequent of each rule depending on its firing strength. Then the second operation is the defuzzification to aggregate the qualified consequents to produce a crisp output of Flexible cost factor from fuzzy output.

The fuzzy inference engine extracts and evaluates rules from the rule base and produces fuzzy outputs. The fuzzy inference engine presented in (Kothari *et al*., 2011) is adopted for the design of Flexible cost factor. In this model, three linguistic terms (e.g., high, low, medium)

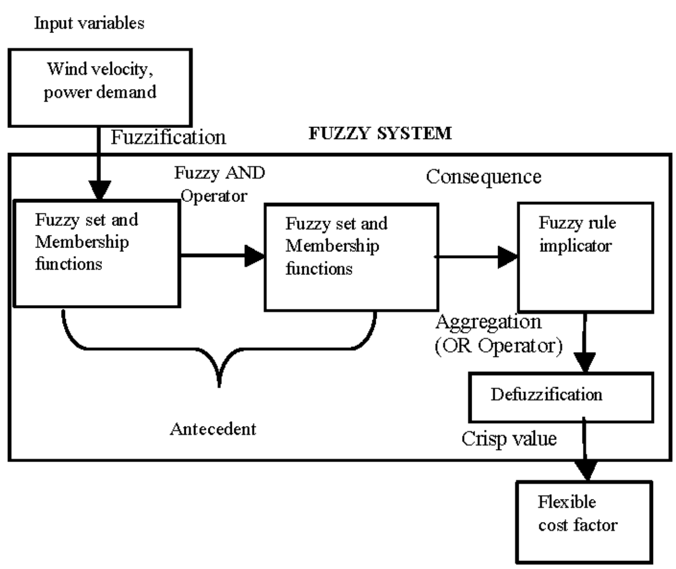

Fig. 3: Fuzzy logic model for flexible cost factor system

Table 3: Linguistic lables for fuzzy parameters

Parameters	Linguistic labels
Wind velocity	Low VEL, medium VEL, high VEL
Power demand	Low DE, medium DE, high DE
Flexible cost factor	Low FF, medium FF, high FF

referred to as fuzzy set, are assigned to each variable (e.g., wind velocity) as shown in Table 3. These fuzzy sets overlap and cover the required range of variation for that variable. The degree of membership of a real valued input (e.g., wind velocity) to a particular fuzzy set A (e.g., low) is given by a membership function μA(x). This transformation of crisp input into a degree of membership in a particular fuzzy set is called fuzzification.

Demarcation for fuzzy parameters

Wind velocity:

$$\begin{aligned} &\text{Low VEL}\left(x; v_{\min,} a\right) = 1, x \le V_{\min} \\ &\frac{a-x}{a-V_{\min}}, V_{\min} \le x \le a; \end{aligned} \tag{4}$$

where , V_{min} is minimum wind velocity and 'a' is upper limit of V_{min}:

$$\begin{aligned} &\text{High VEL}\left(x; V\max, a\right) = 1, V\max \le x; \\ &\frac{x-a}{V\max - a}, a \le x \le V\max; \end{aligned} \tag{5}$$

where, V_{max} is maximum wind velocity and 'a' is lower limit of V_{max}:

$$\begin{aligned} &\text{MedVEL}\left(x; a, V\text{mid}, c\right) = 0, x \le a; \frac{x-a}{V\text{mid} - a}, \\ &a \le x \le V\text{mid}: \frac{c-x}{c - V\text{mid}}, V\text{mid} \le x \le c; 0, c \le x \end{aligned} \tag{6}$$

where:

V_{mid} = medium wind velocity, 'a' is lower limit of V_{mid}

c = The upper limit of V_{mid}

The representation of wind velocity as fuzzy set contains three membership functions, say Low, Medium and High. The generic range of triangular membership functions are shown in Eq. 4-6. Minimum and maximum velocity ranges are decided by the information from the past history of generation according to the wind velocity. These ranges will differ according to the wind power density. If wind power density is more it will result in extended ranges.

Power demand:

$$\begin{aligned} &\text{Low DE}\left(x; D\min, a\right) = 1, x \le D\min; \\ &\frac{a-x}{a - D\min}, D\min \le x \le a; \end{aligned} \tag{7}$$

where , D_{min} is minimum power demand and a is upper limit of D_{min}:

$$\begin{aligned} &\text{HighDE}\left(x; D\max, a\right) =, D\max \le x; \\ &\frac{x-a}{D\max - a}, a \le x \le D\max; \end{aligned} \tag{8}$$

where, D_{max} is maximum power demand and a is lower limit of D_{max}:

$$\begin{aligned} &\text{MedDE}\left(x; a, D\text{mid}, c\right) = 0, x \le a \frac{x-a}{D\text{mid} - a}, a \le x \le D\text{imd}; \\ &\frac{c-x}{c - D\text{mid}}, D\min \le x \le c; 0, \le x \end{aligned} \tag{9}$$

where,

D_{mid} = Medium power demand

a = Lower limit of D_{mid} and

c = Upper limit of D_{mid}

The representation of power demand as fuzzy set contains three membership functions, say low, medium and high. The generic range of triangular membership functions are shown in Eq. 7-9. Minimum and maximum power demand ranges are decided by the information from the past history of power demand in selected areas/states. These ranges will be different for each state. If power demand is the more it will result in extended ranges.

Flexible cost factor:

$$\begin{aligned} &\text{Low FF}\left(x; CF\min, a\right) = 1, x \le CF\min; \\ &\frac{a-x}{a - CF\min}, CF\min \le x \le a; \end{aligned} \tag{10}$$

where , CF_{min} is minimum cost factor and a is upper limit of CF_{min}.

$$\begin{aligned} &\text{MedFF}\left(x; z, CF\text{mid}, c\right) =, x \le a; \frac{x-a}{CF\text{mid} - a}, \\ &a \le x \le CF\text{mid}; \frac{c-x}{c - CF\text{mid}}, CF\text{mid} \le x \le c; 0, c \le x \end{aligned} \tag{11}$$

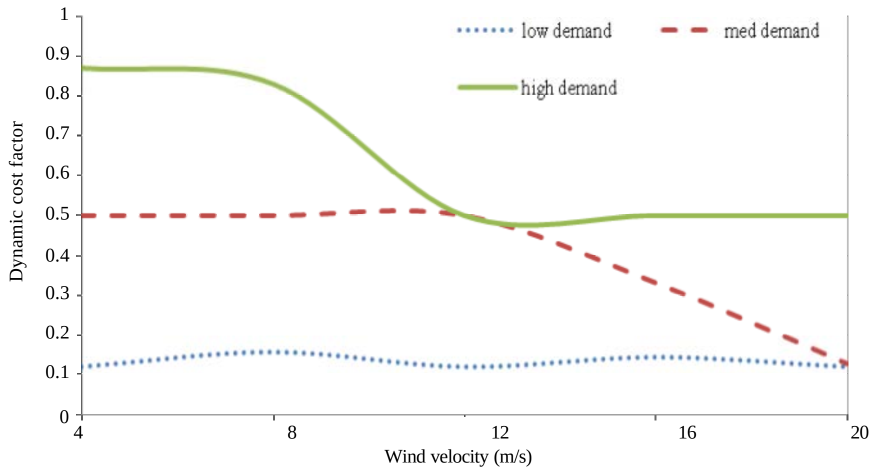

Fig. 4: Fuzzy modeling output of flexible cost factor

Table 4: Fuzzy rules

Power demand	Wind velocity		
	L	M	H
L	L	L	L
M	M	_	L
H	H		M

Where:

Cf_{mid} = Medium cost factor
a = Lower limit of CF_{mid} and
c = Upper limit of Cf_{mid}:

$$\text{HighFF}(x;\text{CFmax},a) = 1, \text{CFmax} \le x; \quad \frac{x-a}{\text{CFmax}-a}, a \le x \le \text{CFmax}; \qquad (12)$$

where,

Cf_{mid} = Medium cost factor
a = Lower limit of CF_{mid} and
c = Upper limit of Cf_{mid}

The representation of cost factor as fuzzy set contains three membership functions say Low, Medium and High. The generic range of triangular membership functions are shown in Eq. 10-12. Minimum and maximum cost factor ranges between 0 and 1 respectively. This factor will be multiplied with the current generic tariff of wind energy.

Fuzzy rules: The antecedent and implication approach used in this research is based on the Mamdani's method. Fuzzy rules are formed based on the following inferences: If power demand is low, whatever be the wind velocity, the cost factor is also low. If power demand is medium and wind velocity is high, the cost factor is low. If wind velocity is low and power demand is high, the cost factor is high. From the above inferences fuzzy rules are formed as shown in Table 4.

In the aggregation process, output fuzzy sets of each rule (produced by inference method) are aggregated to form a single aggregated output. In this research, the rules are aggregated by the min function (conjunctive system of rules) presented in Eq. 13:

$$\mu_{A\cup B(y)} = \text{Min}\left(\mu_{A(y)}, \mu_{B(y)}\right) \text{for } y \in Y \qquad (13)$$

Suppose there are N rules for Flexible cost factors and the fuzzy inference of each rule is represented as FR_i, where i=1, 2, 3..., N. Thus, single aggregated output is obtained by the conjunction of each rule using AND operator:

$$FR = \text{Min}(FR_1, FR_2, FR_3, FR_4 \ldots\ldots, FR_N) \qquad (14)$$

Defuzzification process involves conversion of the output fuzzy variables to numerical or crisp values. In this research centroid defuzzification method is followed. This is given by the algebraic expression:

$$Z^* = \frac{\int \mu\text{DFi}(z).zdz}{\int \mu\text{DFi}(z)dz} \qquad (15)$$

Where Z^* is the crisp output and can be used for Flexible cost function, ith is the degree of membership of ith rule of demand cost factor fuzzy set. Figure 4 shows a summary of the result from fuzzy logic system. In this graph three cases are discussed.

Case 1: When power demand is very low, the other power sources (hydro, thermal, etc.,) whose tariff is less than wind power tariff is enough to meet the power demand. In this scenario, preference of wind power is low hence fuzzy system gives low Flexible cost factor which lies between 0.1 and 0.15. If the system operator needs wind power during low power demand considering environmental aspects, operator may utilize the wind power at low tariff. Case 2: When the power demand is medium, and if all the existing power sources are not capable of meeting the power demand, the system operator prefers wind power at medium Flexible cost factor. The medium Flexible cost factor decreases when wind velocity increases, because at high wind velocity more number of wind energy systems will participate in wind power generation, hence by considering high degree of participation Flexible cost factor is reduced. In this case Flexible cost factor varies between 0.15 and 0.5.

Case 3: When power demand is very high system operator severely needs wind power generation. If it is low wind velocity period, only a few number of wind energy systems will be involved in extracting maximum wind power using Maximum Power Point Tracking (MPPT) technology and the advent of power electronics technology. In the promotion of these wind energy systems, the Flexible cost factor is very high, it will be around 0.9. When wind velocity increases the Flexible cost factor decreases but it will not decrease to a low value, because of very high power demand. Flexible cost factor almost stabilizes to 0.5 during transition from medium range of wind velocity to high range of wind velocity. This scenario gives optimal benefit for WPP. Using fuzzy system, this Flexible cost factor gives optimal wind power tariff during all the seasons.

RESULTS AND DISCUSSION

Implementation of flexible feed in tariff: Each WPP has commercial obligation to export the power generated to intra state transmission system. They will provide an advance declaration of their MW export for each 15 minutes time block for the next day. State Load Dispatch Center (SLDC) will perform the day ahead forecast of power demand and wind velocity and prepare the economic power dispatch schedule. The hourly forecast is also necessary to minimize the forecasting error that can occur in the day ahead forecasting of wind velocity and power demand. System operator of SLDC will carry out the real time operations for grid control and dispatch of electricity within the state through secure and economic operation of the state grid.

If power demand is less than the total generation of all power sources, system operator may turn off the wind mills on consideration of grid security [23]. Flexible feed in tariff is calculated for sum of wind power at every 15 minutes time block at end of that day. Figure 5 illustrates the Flexible Feed in Tariff model implementation.

Case study: India is one of the global leaders in wind power production. Among the states of India, Tamil Nadu contributes 40% of the total wind power produced

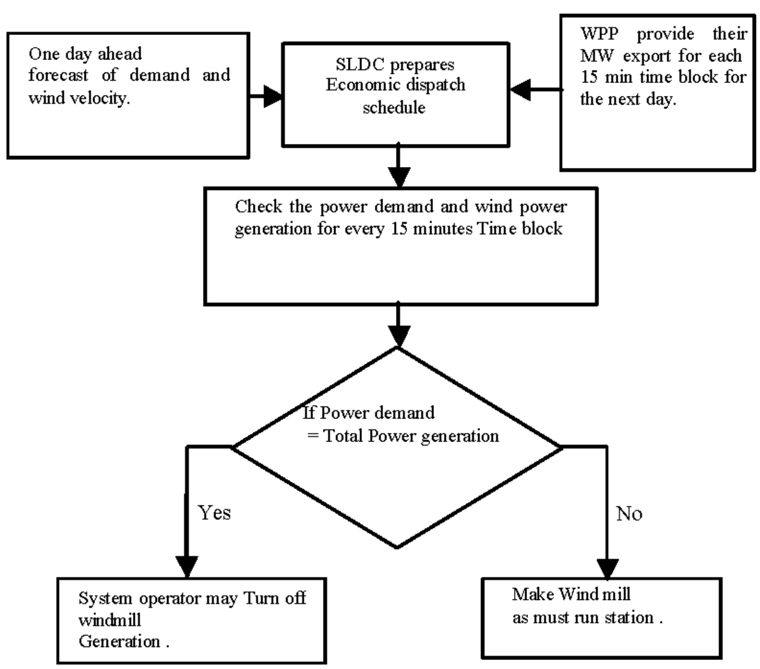

Fig. 5: Implementation procedure of flexible wind tariff mechanism

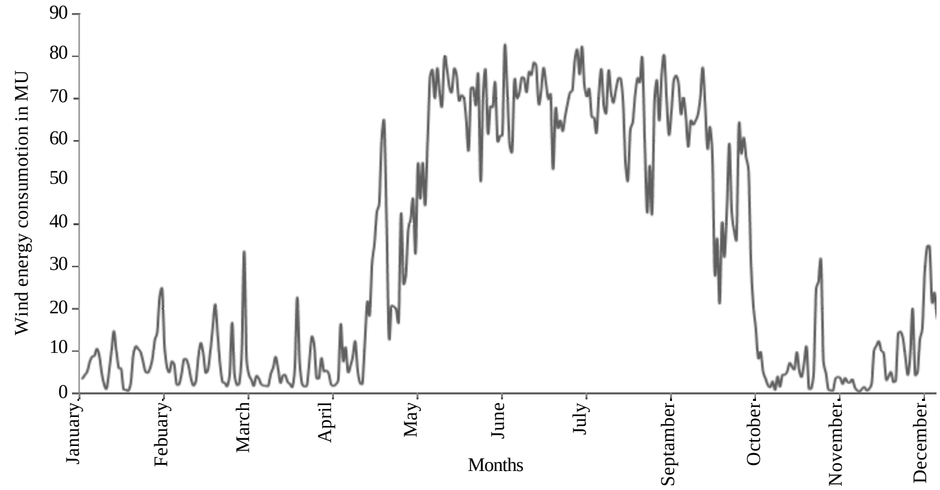

Fig. 6: Wind energy consumption in tamilnadu during the year 2012

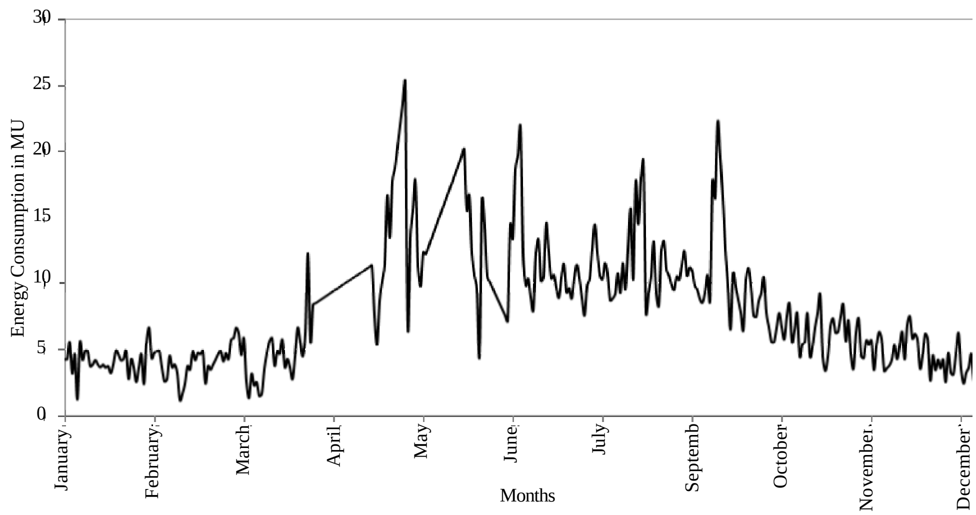

Fig. 7: Wind velocity during the year 2012

factor almost stabilizes to 0.5 during transition from medium range of wind velocity to high range of wind because of high wind power density and policy measures adopted by the state (Agboola *et al*., 2013). In this state, the wind pass location is divided into four bays. They are: shengottah, aralvoimolzhi, kambam and palghat. Given this background, the proposed methodology is implemented for wind mills erected in Tamilnadu.

In this case study, to elaborate and analyze the importance of flexible feed in tariff, the researchs feel that real time daily energy consumption is better than time block power demand.

Tamilnadu State receives wind energy throughout the year and is shown in Fig. 6. From January to April and October to December Tamilnadu receives an average of 10 Million Units of wind energy. Even at low wind velocity, with the participation of few wind mills having advanced technologies maximum power is extracted. This wind power generation resulted in providing some respite from power cuts for the state, but they receive normal fixed feed in tariff and they are not paid any additional incentives for handling this critical situation. During peak wind seasons, wind energy almost satisfies 25% of the power demand.

During the monsoon period (May to September) Tamilnadu experiences high wind season as shown in Fig. 7. Hence, the state generates maximum wind power. In the present situation, during high wind season because of the constraints in the transmission system and to contain the frequency with in 50.2 Hz as per [18], the wind power could not be utilized fully and results in backing down of the wind generation. From these data, the wind velocity range for fuzzy model is fixed from 4m/s-20m/s.

Tamilnadu receives maximum supply from hydro, thermal and wind sources. Apart from this, the power demand is balanced by additional generation from Captive Power Plants (CPP), IPP, the purchase of power from private parties and power exchange. Average consumption of Tamilnadu in the year 2012 is 254.06 Million Units (MU). During the year 2012, it was not able to meet the power demand; the actual energy shortage was 17.5% which resulted in regular power holidays, load shedding during many days and purchase of power from private parties at high cost.

The fixed tariff for wind power in tamilnadu is Rs.3.51/unit; Independent Power Producer (IPP) is approximately Rs.7.16/unit and power from private parties is approximately Rs.16/unit. The projected consumption of power (Load shedding artificially suppresses actual power consumption) excluding load shedding in the year 2012 is shown in Fig. 8. From these data, the power consumption range of Tamilnadu for fuzzy model is fixed from 160 MU-290 MU.

Based on these data, Flexible cost factor is calculated by implementing fuzzy system. Flexible cost factor for the year 2012 of the selected state is shown in Fig. 9. January to April is low wind season, but the demand of Tamilnadu is always maintained as almost a constant, i.e., maximum power consumption except during festival holidays, hence cost factor during this period ranges from 0.80-0.83. During this period, if WPP support the power sector, they can get high tariff due to high Flexible cost factor. During peak wind seasons, every WPP contributes to the grid; by increasing the competition level, the Flexible cost factor is almost maintained at a low value of 0.5 except for a few days. After the end of high wind season, winter starts, hence power consumption is little lesser than it was during the previous period. Due to low wind velocity, in this period flexible cost factor is maintained at an average of 0.80.

The proposed method ensures power purchase at a reduced cost than the purchase cost from IPP and private parties, as presented in Fig. 10. The cost incurred for power during the year 2012 is calculated for three cases i.e., for implementation of flexible feed in tariff, purchase of power from IPPs and private parties and are compared with the current feed in tariff and is presented in Fig. 11.

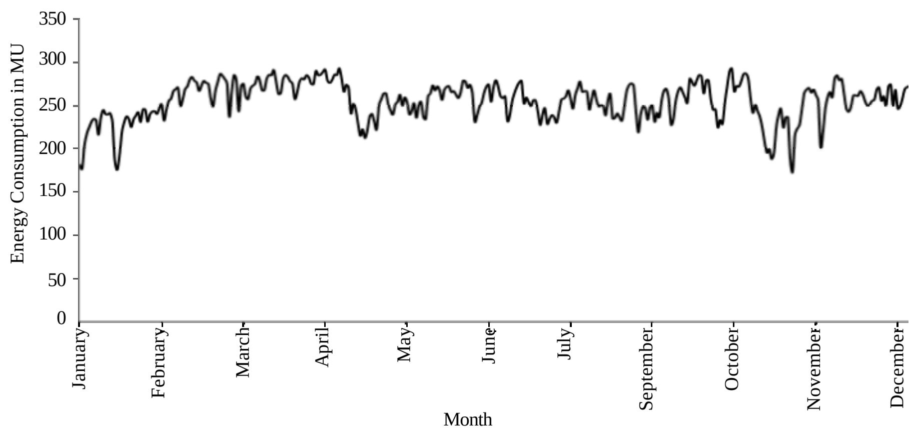

Fig. 8: Energy consumption of tamilnadu state during the year 2012

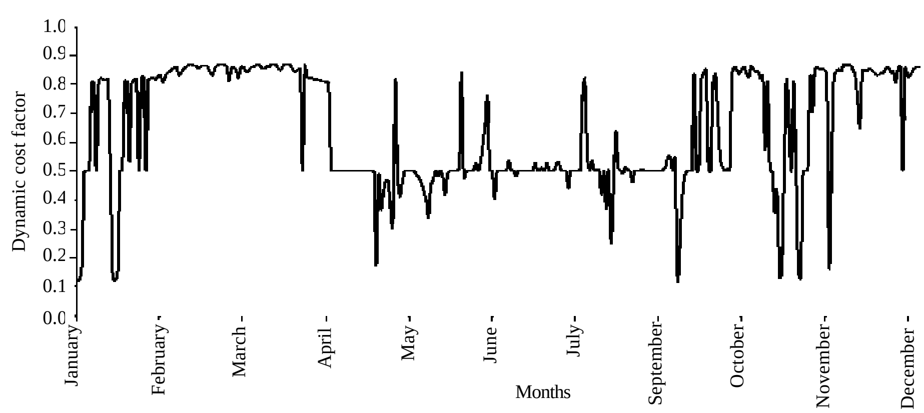

Fig. 9: Flexible cost factor during the year 2012

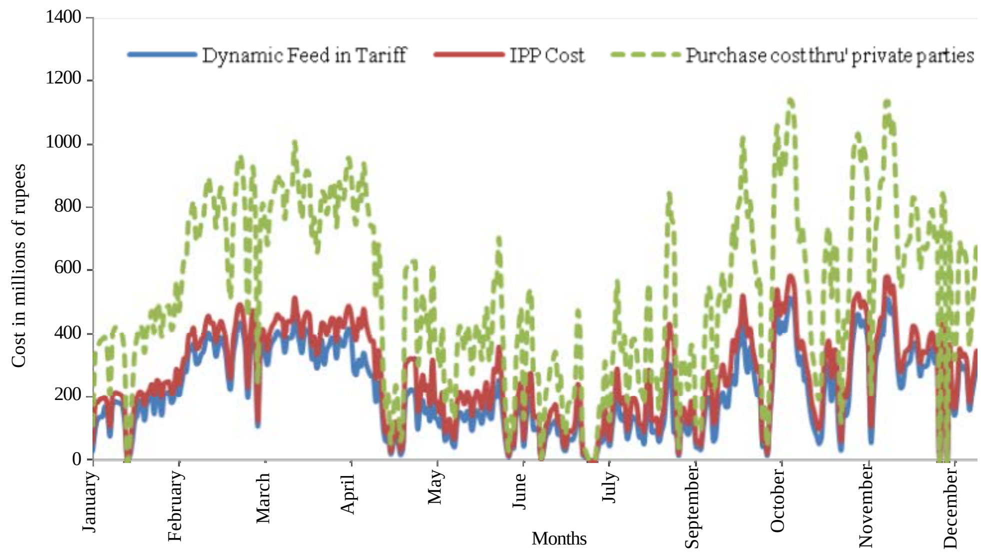

Fig. 10: Comparison between flexible feed in tariff, IPP cost and private cost

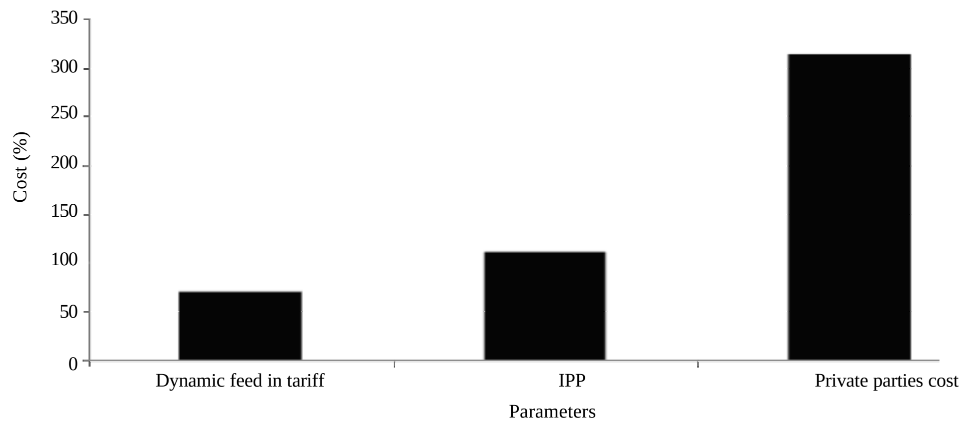

Fig. 11: Comparison of flexible feed in tariff, IPP and private parties cost with respect to current feed in tariff

From this figure it can be observed that flexible feed in Tariff is lesser than tariff of IPP and private parties, but it is greater than the fixed feed in tariff of wind in Tamil Nadu. Hence, WPP receives higher tariff than the current tariff, it will not result in any loss to the Government. Hence, flexible feed in tariff guarantees as an optimal tariff for both the Government and WPPs. This analysis may help to initiate new wind projects to increase power generation and provide uninterrupted power supply at a comparatively lower cost instead of purchasing power from private parties and also helps in reduction of the consumption of fossil fuels.

CONCLUSION

This study develops a novel tariff mechanism named flexible feed in tariff model for wind power. In this, flexible cost factor is computed using fuzzy logic considering the variable nature of wind velocity and daily power demand. The proposed model is then numerically implemented for wind mills located in Tamil Nadu State.

From the result, the proposed tariff will arrive at a cost that is less than that of other tariff mechanisms which is benefit to central authority and also it is higher than current fixed tariff mechanism which is benefit to Wind power producers.

Hence, this tariff promotes investments in wind energy sector and also reduces the power purchase from private parties and IPP which may result in polluting the environment. Thus, it is beneficial to both central authority and wind power producers.

Appendix A

Working sheet of tariff computation

Years	A	B	C	D	E X10^5	F	G
1	5.566	49.31	22	34.2	111.1	23.7	4.67
2	5.844	49.31	22	34.2	111.3	23.7	4.68
3	6.136	44.37	22	34.2	106.7	23.7	4.49
4	6.443	39.44	22	34.2	102.1	23.7	4.29
5	6.765	34.51	22	34.2	97.51	23.7	4.10
6	7.103	29.58	22	34.2	92.92	23.7	3.91
7	7.458	24.65	22	34.2	88.34	23.7	3.71
8	7.831	19.72	22	34.2	83.78	23.7	3.52
9	8.223	14.79	22	34.2	79.25	23.7	3.33
10	8.634	9.861	22	34.2	74.73	23.7	3.14
11	9.066	4.930	22	34.2	70.23	23.5	2.98
12	9.519	4.105	22	34.2	65.75	23.3	2.82
13	9.995	3.987	22	34.2	66.23	23.0	2.87
14	10.49	3.176	22	34.2	66.73	22.8	2.92
15	11.02	3.021	22	34.2	67.25	22.6	2.97
16	11.57	3.009	22	34.2	67.80	22.3	3.03
17	12.14	2.765	22	34.2	68.38	22.1	3.08
18	12.76	2.125	22	34.2	68.99	21.9	3.14
19	13.39	2.081	22	34.2	69.63	21.7	3.20
20	14.06	1.978	22	34.2	70.30	21.5	3.27

Average feed in tariff for 20 years 3.51. A: O and M charges at 1.10% for machinery on 85% of capital investment and at 0.22% for civil works on 15% of capital investment with 5% escalation every year from 2nd year (Rs in Lakhs); B: Interest on loan @ 12.25% (Rs in Lakhs); C: Depreciation at 4.5% on 85% of capital investment (Rs in Lakhs); D: Total Cost(Rs in Lakhs); E: Units generated for 1 MW (Kwh); F: Cost per unit (Rs.)

REFERENCES

Agboola, A.H., A.J. Gabriel, E.O. Aliyu and B.K. Alese, 2013. Development of a fuzzy logic based rainfall prediction model. Int. J. Eng. Tech., 3: 427-435.

Dominguez, R., A.J. Conejo and M. Carrion, 2015. Toward fully renewable electric energy systems. Power Syst. IEEE. Trans., 30: 316-326.

Henriksen, L.C., 2013. Wind energy literature survey no. 27. Wind Energy, 16: 159-161.

Hetzer, J., D.C. Yu and K. Bhattarai, 2008. An economic dispatch model incorporating wind power. IEEE Trans. Energy Convers., 23: 603-611.

Indian Wind Energy Association, 2012. Wind energy program in India http://www.inwea.org/aboutwindenergy.htm

Khare, V., S. Nema and P. Baredar, 2013. Status of solar wind renewable energy in India. Renewable Sustainable Energy Rev., 27: 1-10.

Kothari, D.P., K.C. Singal and R. Ranjan, 2011. Renewable Energy Sources and Emerging Technologies. 2nd Edn., PHI Learning Pvt. Ltd., New Delhi, India, ISBN: 978-81-203-4470-9, Pages: 434.

Mathews, J., 2007. Seven steps to curb global warming. Energy Policy, 35: 4247-4259.

Rao, K.U. and V.V.N. Kishore, 2009. Wind power technology diffusion analysis in selected states of India. Renewable Energy, 34: 983-988.

Sharma, A., J. Srivastava, S.K. Kar and A. Kumar, 2012. Wind energy status in India: A short review. Renewable Sustainable Energy Rev., 16: 1157-1164.

Singh, S.N., B. Singh and J. Ostergaard, 2009. Renewable energy generation in India: Present scenario and future prospects. Proceedings of the 2009 IEEE Power and Energy Society General Meeting, July 26-30, 2009, IEEE, New York, USA., ISBN: 978-1-4244-4241-6, pp: 1-8.

Xie, Y., Y. Feng and Y. Qiu, 2013. The present status and challenges of wind energy education and training in China. Renewable Energy, 60: 34-41.

Zhao, Y., K.K. Tang and L.L. Wang, 2013. Do renewable electricity policies promote renewable electricity generation? Evidence from panel data. Energy Policy, 62: 887-897.