International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-04, Issue-05, Aug 2018

Application of Gompertz Model for Technology Diffusion Analysis of Wind Power

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Abstract **In India, the wind power generation has gained a high level of awareness and acceptability. Different states of India have different wind power installation capacity depending on availability of wind throughout the year. The state level data of cumulative wind power installed capacity is used to obtain the diffusion parameters using Gompertz model. In this paper the theory of diffusion of innovation is used to study the development of wind power technology in different states of India. The future growth pattern of technical wind potential of five Indian states Rajasthan, Gujarat, Karnataka, Maharashtra are predicted and analyzed using Gompertz model.**

Keywords —Diffusion, Wind, Power, Gompertz model, Prediction

I. INTRODUCTION

Energy is the key factor for industrialization, development, economic growth and improvement of quality of life in society. A major part of this energy requirement depends on conventional energy sources which are based on fossil fuels. Conventional energy sources based on hydrocarbon oil, coal, and natural gas have proven to be highly effective tools of economic progress, but at the same time causing huge carbon emissions which leads to harm the environment and to human health. The rapid growth in the energy consumption rate is the main cause of energy shortage, as well as energy resources are depleting worldwide. Electricity shortage is very common in country like India where most of the population has no access to modern energy services. According to International Energy

Agency, more than 28 percent share of the world's total energy will be consumed in India and China by the year 2030 [1].Therefore a significant amount of energy must come from renewable sources. Renewable energy is reliable, clean and ample source of energy. It includes solar, wind, tidal, geothermal energy. Among these renewable energy sources wind power is one of the most viable alternatives to reduce dependence on fossil fuels. Wind energy is the kinetic energy associated with movement of large masses of air. This motion results from irregular heating of the atmosphere by the sun, creating temperature, density and pressure difference. Wind power is the conversion of wind energy into a useful form of energy using wind turbines to make electrical power, wind mills for mechanical power [2]. Wind has considerable potential as a global clean energy source, being widely available, and producing no pollution during power generation. Wind energy has been one of primary energy sources for milling grain, and pumping water for several millennia. Over 2000 years ago windmills used in China, India and Persia [1].

II. WIND ENERGY IN INDIA

India has good potential of wind throughout the country. Rapidly growing demand of energy forces India to search for renewable energy sources such as wind energy. Wind energy has been the fastest growing renewable energy sector in the country. India is blessed with 7517km of coastline and 320000 KM^2 of Thar desert where wind blow year-round. India is the 3rd largest annual wind power market in the world [2] and provides great business opportunities for both domestic and foreign investors. India occupies the forth place in the world in installing wind energy, after China, U.S. and Germany [3]. India for renewable energy related matter. Centre for Wind Energy Technology (C-WET) is responsible for the assessment wind resource in the country. As a result of scientific evaluation of wind resources [2, 5-7] throughout the country, wind power has emerged as a feasible and cost effective option for power generation. Table 1 shows Global installed wind power as on March 2016 [8].State wise potential has been provided in Table 2.

Table no.1 Global Installed Wind Power [3]

S. No.	Country	Cumulative (End 2016) MW	New Installed (2017) MW	Cumulative (End 2017) MW
1.	China	168732	19500	188232
2.	USA	82060	7017	89077
3.	Germany	50019	6581	56132
4.	India	28700	4148	32848
5.	Spain	23075	96	23170

 DOI : 10.18231/2454-9150.2018.0622

Table no.2 Wind Power capacity of Different States of India [8]

States / UTs	Estimated potential (MW)
Andaman & Nicobar	2
Andhra Pradesh	5394
Arunachal Pradesh	201
Assam	53
Bihar	-
Chhattisgarh	23
Dieu Damn	-
Gujarat	10609
Haryana	-
Himachal Pradesh	20
Jharkhand	-
Jammu & Kashmir	5311
Karnataka	8591
Kerala	790
Lakshadweep	16
Madhya Pradesh	920
Maharashtra	5439
Manipur	7
Meghalaya	44
Nagaland	3
Orissa	910
Pondicherry	-
Rajasthan	5005
Sikkim	98
Tamil Nadu	5374
Uttarakhand	161
Uttar Pradesh	137
West Bengal	22
Total	49130

III. DIFFUSION

The diffusion of an innovation is a process by which an innovation is communicated through certain channels over time among the members of a social system [5]. Innovation, channel of communication, time and social system are the elements of diffusion of an innovation. Technology diffusion is how widespread the use of technology is in an organization or a social system. Diffusion model had been mostly used to forecast the demand of new technology. The general pattern of technology adoption is an S-shaped curve when the percentage of the installed base captured by the new technology is plotted over time. The curve generally comprises of three distinct phases:

i) A slow growth over a long period- this is introduction stage, the process staff learns the new production technology.

ii) A rapid take-off period –After introduction stage the staff has already learned the new production technology and gets more experiences a rapid take-off occur during this period.

iii) A flattening of the curve-this indicate a near completion of diffusion. For the maturity stage, staff has already made plentiful experience and learned a practiced operational skill, and product quality grows up to maximum and tends a stable state.

There are several instances of occurrence of multiple S curves for the same technology/product class which signify introduction of new models in the market. The estimated member of adopters of an innovation defines the 'market potential'.

Utilization of wind power is extremely site specific and the success of wind technology presumes that the energy demand exists at that point of time and location. Currently ten States of India, namely, Tamil Nadu, Karnataka, Andhra Pradesh, Gujarat, Rajasthan, Maharashtra, Madhya Pradesh, West Bengal, Kerala, and Orissa are implementing major wind energy programmes. However, the four States – Maharashtra, Gujarat, Tamil Nadu and Andhra Pradesh which account for 60% of the total potential have 90% of the total installed wind generation capacity. The rates of diffusion and achievements have been different for different states depending on specific issues such as grid quality, availability of land for installations, distance from the generation point to feed-in point, etc

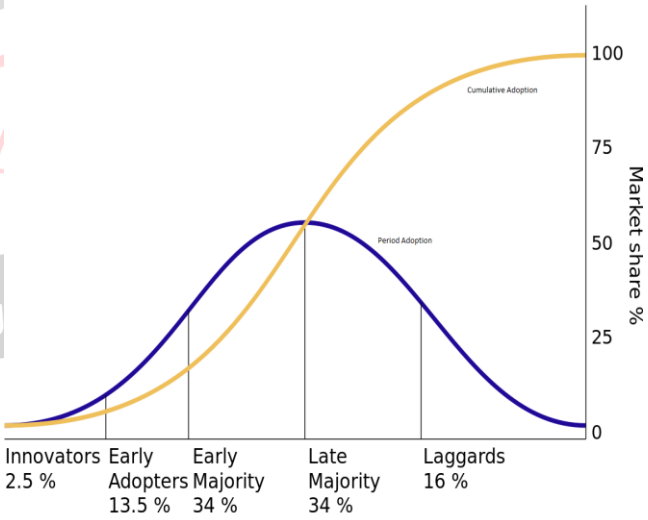

Fig- 1 Diffusion of an innovation

IV. MATHEMATICAL PRESENTATION OF GOMPERTZ MODEL

The diffusion of wind power in selected states of India can be forecasted using the Gompertz growth model [9]

$$N(t) = M\, e^{\left(-b\left(e^{(-at)}\right)\right)} \qquad (1)$$

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Where N(t) is the cumulative installed capacity of wind power projects in a state of country at time t ,M is the total wind power potential of the state, parameter b is related to the time that the growth reaches 37% from its saturation level [7], where a will measures the speed of the adoption process.

The model parameter values are required for forecasting the diffusion path of a new energy technology. If technology market penetration data is available the regression coefficients" **b** "and "**a**" can be estimated by a exponential regression of the loglog form of Eq. (1) as given below

$$\ln\left(\frac{N(t)}{M}\right) = -b\, e^{(-at)} \qquad (2)$$

$$\ln\left(\frac{M}{N(t)}\right) = b\, e^{(-at)} \qquad (3)$$

V. Calculation and Result

Cumulative wind potential installed in different states of India from yr 2002-2003 to 2016-17 [4] ,[10]-[11] is as shown in Table 4.1. Based on algorithms expressed in section 3, the parameters a & b for wind potential installed in Rajasthan, Gujarat, Maharashtra & Karnataka states of India are found using Excel as shown in table 4.2 and fig 4.1 and 4.2. Using these parameters for different states cumulative wind potential installed from year 2002-03 to 2016-17 can be found out. Fig 4.3 to 4.6 shows the comparison of actual wind power installed with predicted wind power for Rajasthan, Gujarat, Karnataka and Maharashtra states of India. As the values of R^2 for Rajasthan, Gujarat, Karnataka and Maharashtra are 0.944, 0.978, 0.977 and 0.946 respectively and actual power is nearly equal to predicted power, the Gompertz model can be applied to predict wind power installed.

Using these parameters for different states cumulative wind potential installed from year 2018 to 2020 can be predicted for Rajasthan, Gujarat, Karnataka and Maharashtra. Table 4.3 shows the predicted cumulative wind potential installed from year 2018 to 2020 for Rajasthan, Gujarat, Karnataka and MaharashtraReferences

Table no.3 Cumulative wind potential installed in different states of India from yr 2002-13 to 2016-17 [4, 10, 11]

S.No.	Year	Cumulative Installed Capacity as on 31 march 2017(MW)			
		Rajasthan	Gujarat	Maharashtra	Karnataka
1	02-03	61.37	187.6	402.3	124.9
2	03-04	175.77	216.5	408.5	209.8
3	04-05	279.51	268	457.3	411.3
4	05-06	352.785	352.6	1002.4	555.1
5	06-07	464.535	636.6	1487.7	821.1
6	07-08	534.985	1253	1755.9	1011.4
7	08-09	734.585	1566.6	1938.9	1327.4
8	09-10	1084.585	1863.7	2077.8	1472.8
9	10-11	1521.285	2176.5	2316.9	1726.9
10	11-12	2066.935	2966.4	2733.4	1933.6
11	12-13	2698.935	3174.7	3022	2135.3
12	13-14	2796.935	3454.5	4096.5	2318.3
13	14-15	3320.435	3581.4	4369.95	2548.8
14	15-16	4005.935	3948.61	4653.83	2639.55
15	16-17	4281.9	5223.61	4772.82	3751.15

Table no. 4 Parameters of Gompertz model for different states

S. No.	Constant	Rajasthan	Gujarat	Maharashtra	Karnataka
1	M (MW)	5005	10609	5439	8591

 DOI : 10.18231/2454-9150.2018.0622

2	b	6.789	4.913	4.324	4.207
3	a	0.22	0.12	0.21	0.10
4	R^2	0.944	0.978	0.946	0.977

Table no. 5 forecast Cumulative wind potential installed from year 2018 to 2020

S. No.	Year	Rajasthan	Gujarat	Maharashtra	Karnataka
1	2017-18	4093.854	5737.248301	4680.476686	3674.203933
2	2018-19	4259.581	6150.247425	4815.545396	3983.518835
3	2019-20	4397.42	6541.355879	4927.885063	4285.780665
4	2020-21	4511.257	6909.000755	5020.86614	4578.996927

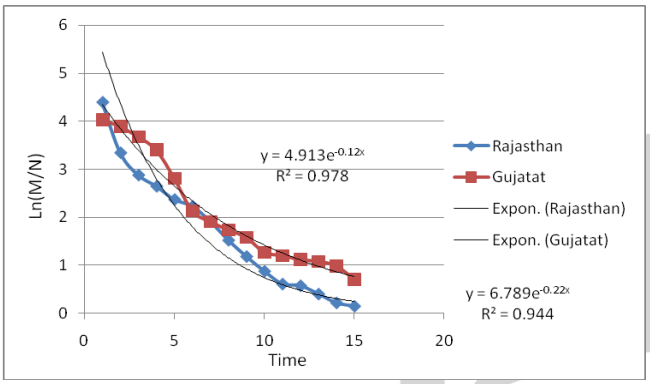

Fig 2 – Exponential Regression using Excel for Rajasthan and Gujarat

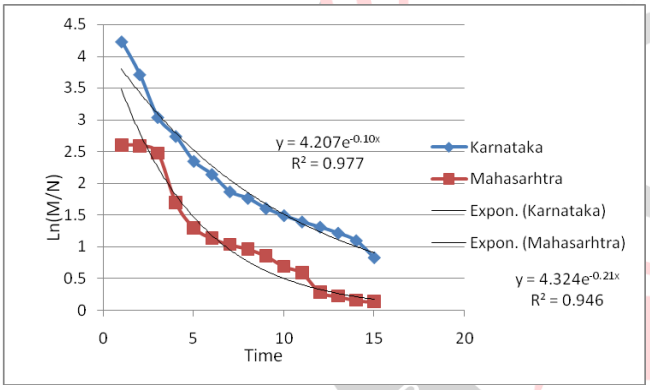

Fig 3 - Exponential Regression using Excel for Maharashtra and Karnataka

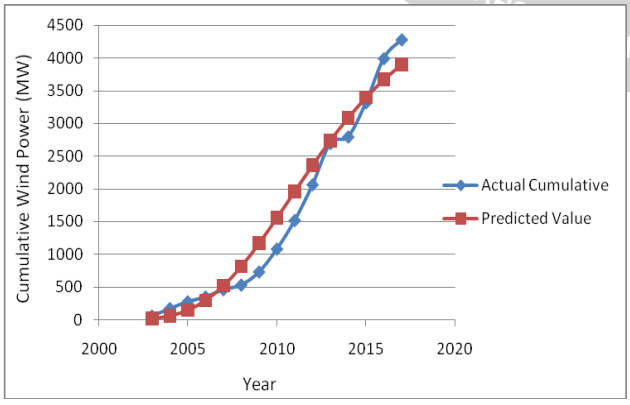

Fig 4 Comparison of Actual Power with Predicted Power for Rajasthan

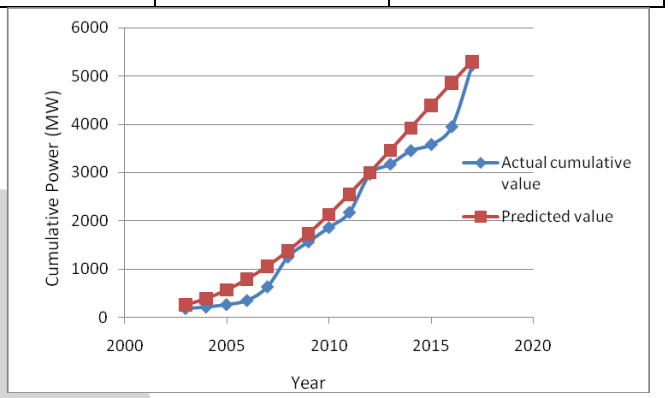

Fig 5 Comparison of Actual Power with Predicted Power for Gujarat

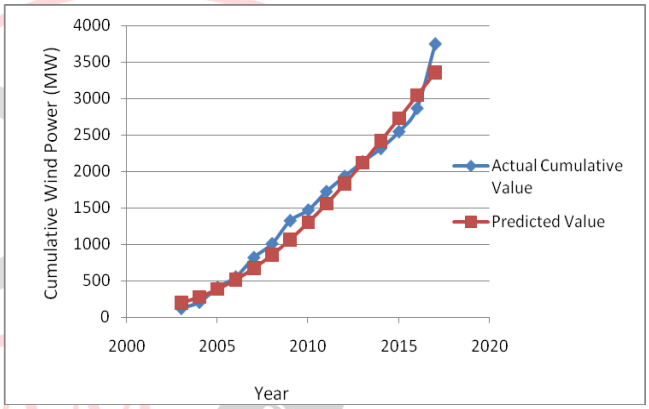

Fig 6 Comparison of Actual Power with Predicted Power for Karnataka

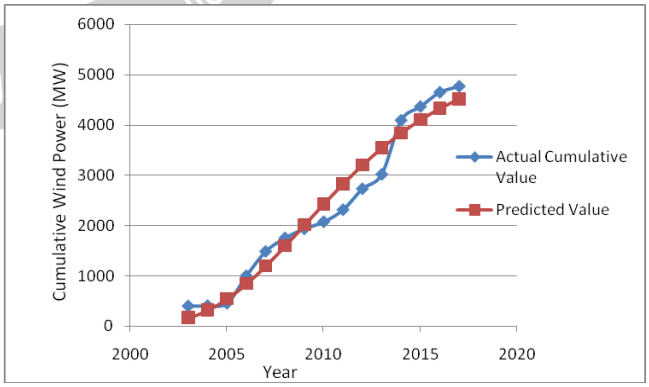

Fig 7 Comparison of Actual Power with Predicted Power for Maharashtra

VI. CONCLUSION

The study result shows that applying Gompertz model to forecast short term cumulative wind potential installed

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results in excellent prediction of wind potential. The result of this study is important in forecasting cumulative wind potential installed. Excellent prediction can be obtained by applying Gompertz model to forecast short term cumulative wind power. Predicting the wind power is very significance for state to prepare the development strategy. The policymaker can make suitable policies to make the economic firmly developed.

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