Estimation of reliability evaluation of Wind Power plant connected to power grid: An Analysis

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Abstract : The grid was also able to keep up voltage and frequency, and was able to provide any reactive power that was needed. India of 58 numbers of 225 KW each (13.5 MW).The reliability evaluation result of 10 units of Dewas plant connected to eastern grid were predictable. The estimates were based on the performance data of the individual units over a period of one year. The power produced by the wind turbine increases from zero at the threshold wind speed (cut in speed) (usually around 5m/s but varies with site) to the maximum at the rated wind speed. Above the rated wind speed, (15 to 25 m/s) the wind turbine continues to produce the same rated power but at lower efficiency until shut down is initiated if the wind speed becomes dangerously high, i.e. above 25 to 30m/s (gale force). The exact specifications for energy capture by the turbine depend on the distribution of wind speed over the year at the individual site. Air density has a significant effect on wind turbine performance. The power available in the wind is directly proportional to air density. As air density increases the available power also increases. Air density is a function of air pressure and temperature. It increases when air pressure increases or the temperature decreases. Both temperature and pressure decrease with increasing elevation. Consequently changes in elevation produce a profound effect on the generated power as a result of changing in the air density.
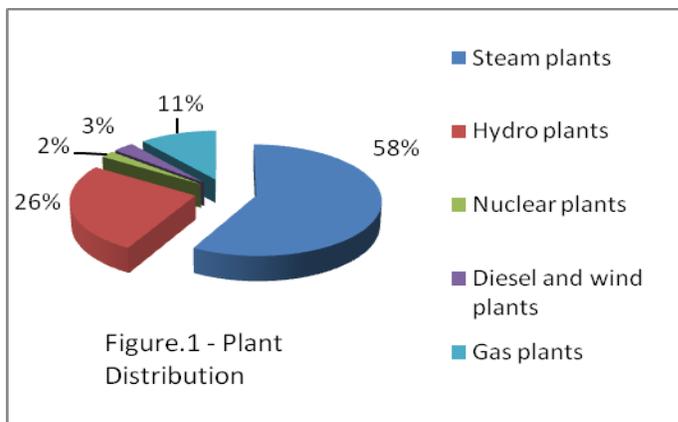
1. Introduction:

Fig. 1. Different type of Power plant

The major sources of electrical energy, in India, are the fossil fuels and water. There are no immediate prospects for large scale utilization of alternate sources of energy like sun, wind, tides etc. for generation of electrical energy. The three types of fossil fuels used in power plants are coal, oil and gas. As it common to know, coal is the predominant source of energy in India and many other countries. Coal contains moisture, carbon, hydrogen, sulphur, nitrogen, oxygen and ash.

The liquid fuels are obtained by refining the crude oil which contains about 84 to 87% carbon, 11 to 16% hydrogen, and oxygen, nitrogen, sulphur etc. Gaseous fuels are either natural gas or manufactured gas (water gas or producer gas). The manufactured gas is costly and, therefore, not used for power generation. The fuels used in nuclear reactors are natural uranium, lightly enriched uranium dioxide and plutonium.

2. WIND POWER GENERATION

The kinetic energy per unit time, or power, from wind is given by Equation (1). Wind power is proportional to the cube of the wind velocity.

$$\textit{Power of Wind} = 1/2 * \rho * A * V^3 \qquad \textbf{(1)}$$

Where, P is power in watts, ρ is air density in kg/m3, A is area exposed to the wind (m2), and V is wind speed in m/s.

The actual power production potential of a wind turbine must take into account the fluid mechanics of the flow passing through a power producing rotor, the aerodynamics and efficiency of the combination of rotor and generator. In practice, a maximum of about 45% of the available wind energy is harvested by the best modern wind turbines. Power output from wind turbine can be seen in Equation (2).

$$\textit{Wind Turbine Power Output} = 1/2 * \rho * A * Cp * V^3 * Ng * N\,b \qquad \textit{(2)}$$

where, P is power in watts, ρ is air density in kg/m3, A is area exposed to the wind (m2), V is wind speed in m/s, is performance coefficient (Maximum 0.59), Ng is generator efficiency

IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 2 Issue 3, March 2015.

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ISSN 2348 – 7968

(80% on average for grid-connected induction generators), and N b is gearbox and bearings efficiency (Maximum 95%). p

The power produced by a wind turbine can be shown by a power curve. The power curve of a wind turbine is a function that indicates how large the electrical power output will approximately be for the turbine at different wind speeds. The power curve illustrates three important characteristic velocities:

♦ Rated wind speed: the wind speed at which the rated power of a wind turbine, generally the maximum power output of a generator at highest efficiency, is produced.

♦ Cut-in wind speed: the minimum wind speed at which a generator starts delivering power.

♦ Cut-out wind speed: the maximum wind speed at which the turbine is allowed to produce power, usually limited by engineering design and safety constraints. No power will be produced by a wind turbine beyond the cut-out speed.

The power curve of GE 3.6 MW offshore series wind turbine, where rated speed is 14 m/s, cut-in speed is 3.5 m/s and cut-out speed is 27 m/s.
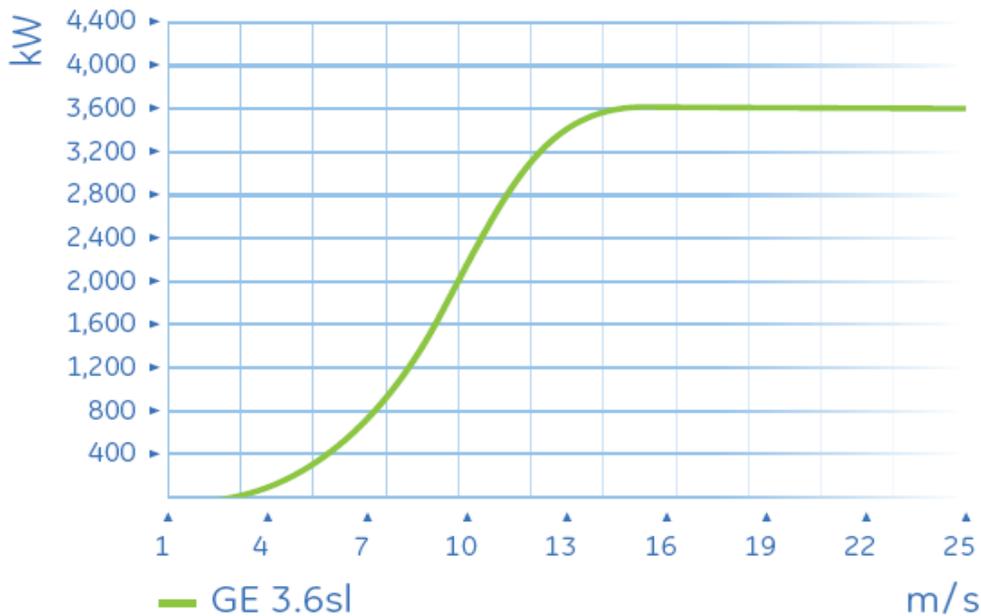

Fig.2 Power Vs Wind speed

A group of wind turbines at the same location are interconnected with a medium voltage power collection system and communication networks, which forms a wind farm. Figure 4.1.2 shows a typical configuration of a wind farm. The power generated from individual turbine are aggregated and delivered to major power systems from the substation at wind farm through transmission systems. A wind farm may be located offshore to take advantage of strong and steady winds blowing over the surface of an ocean or lake.
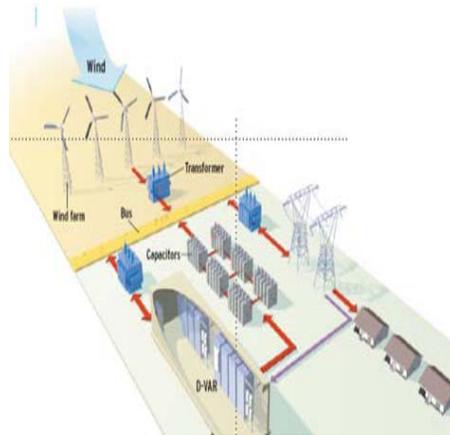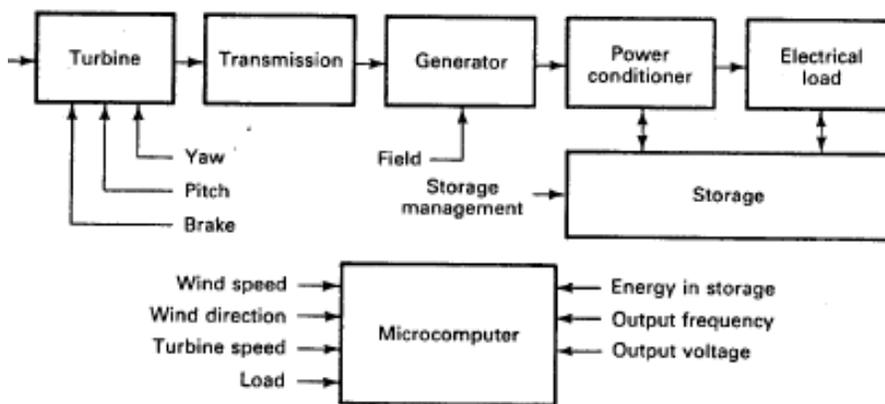

Fig. 3 Model of Wind Power Plant

3. ASYNCHRONOUS SYSTEM

In the previous two chapters, we examined combinations of wind turbines, transmissions, And generators connected to the electrical grid. The electrical grid was assumed to be able to Accept all the power that could be generated from the wind.

The grid was also able to maintain voltage and frequency, and was able to supply any reactive power that was needed. When we disconnect ourselves from the grid, these advantages disappear and we must compensate by adding additional equipment. The wind system design will be different from the synchronous system and will contain additional features.

Block diagram of asynchronous electrical system. In this system, the microcomputer accepts inputs such as wind speed and direction, turbine speed, load requirements, amount of energy in storage, and the voltage and frequency being delivered to the load. The microcomputer sends signals to the turbine to establish proper yaw (direction control) and blade pitch, and to set the brakes in high winds. It sends signals to the generator to change the output voltage, if the generator has a separate yield. It may turn on on critical loads in times of light winds and it may turn on optional loads in strong winds. It may adjust the power conditioner to change the load voltage and frequency. It may also adjust the storage system to optimize its performance.

It should be mentioned that many wind electric systems have been built which have worked well without a microcomputer. Yaw was controlled by a tail, the blade pitch was exceeding, and the brake was set by hand. The state of charge of the storage batteries would be checked once or twice a day and certain loads would be either used or not used depending on the wind and the state of charge. Such systems have the advantages of simplicity, reliability, and minimum cost, with the disadvantages of regularly requiring human attention and the elimination of more nearly optimum controls which demand a microcomputer to function. The microcomputer and the necessary sensors tend to have a exceed cost regardless of the size of turbine. This cost may equal the cost of a 3-kW turbine and generator, but may only be ten percent of the cost of a 100 kW system. This makes the microcomputer easier to justify for the larger wind turbines.

The asynchronous system has one rather interesting mode of operation that electric utilities do not have. The turbine speed can be controlled by the load rather than by adjusting the turbine. Electric utilities do have some load management capability, but most of their load is not controllable by the utilities. The utilities therefore adjust the prime mover input (by a valve in a steam line, for example) to follow the variation in load. That is, supply follows demand. In the case of wind turbines, the turbine input power is just the power in the wind

IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 2 Issue 3, March 2015.

www.ijiset.com

ISSN 2348 – 7968

and is not subject to control. Turbine speed still needs to be controlled for optimum performance, and this can be accomplished by an electrical load with the proper characteristics, as we shall see. A microcomputer is not essential to this mode of operation, but does allow more edibility in the choice of load. We can have a system where demand follows supply, an inherently desirable situation.

As mentioned earlier, the variety of equipment in an asynchronous system is almost limitless. The generator may be either ac or dc. A power conditioner may be required to convert the generator output into another form, such as an inverter which produces 60 Hz power from dc. The electrical load may be a battery, a resistance heater, a pump, a household appliance, or even exotic devices like electrolysis or fertilizer cells. Not every system requires a power conditioner. For example, a dc generator with battery storage may not need a power conditioner if all the desired loads can be operated on dc. It was not uncommon for all household appliances to be 32 V dc or 110 V dc in the 1930s when small asynchronous wind electric systems were common. Such appliances disappeared with the advent of the electrical grid but started reappearing in recreational vehicles in the 1970s, with a 12-V rating. There are no serious technical problems with equipping a house entirely with dc appliances, but costs tend to be higher because of the small demand for such appliances compared with that for conventional ac appliances. An inverter can be used to invert the dc battery voltage to ac if desired.

4. ASYNCHRONOUS (INDUCTION) GENERATORS

Most wind turbines in the world use a so called three phase asynchronous (cage wound) generator, also called an induction generator to generate alternating current. This type of generator is not widely used outside the wind turbine industry, and in small hydropower units, but the world has a lot of experience in dealing with it anyway:

The curious thing about this type of generator is that it was really originally designed as an electric motor. In fact, one third of the world's electricity consumption is used for running induction motors driving machinery in factories, pumps, fans, compressors, elevators, and other applications where you need to convert electrical energy to mechanical energy.

IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 2 Issue 3, March 2015.

www.ijiset.com

ISSN 2348 – 7968

One reason for choosing this type of generator is that it is very reliable, and tends to be comparatively inexpensive. The generator also has some mechanical properties which are useful for wind turbines. (Generator slip, and a certain overload capability).

5. THE CAGE MOTOR

The key component of the asynchronous generator is the cage rotor. (It used to be called a squirrel cage rotor but after it became politically incorrect to exercise your domestic rodents in a treadmill, we only have this less captivating name).

It is the rotor that makes the asynchronous generator different from the synchronous generator. The rotor consists of a number of copper or aluminum bars which are connected electrically by aluminum end rings.

In the picture at the top of the page you see how the rotor is provided with an "iron" core, using a stack of thin insulated steel laminations, with holes punched for the conducting aluminum bars. The rotor is placed in the middle of the stator, which in this case, once again, is a 4-pole stator which is directly connected to the three phases of the electrical grid.

5. MOTOR OPERATION

When the current is connected, the machine will start turning like a motor at a speed which is just slightly below the synchronous speed of the rotating magnetic field from the stator. Now, what is happening?

If we look at the rotor bars from above (in the picture to the right) we have a magnetic field which moves relative to the rotor. This induces a very strong current in the rotor bars which offer very little resistance to the current, since they are short circuited by the end rings.

The rotor then develops its own magnetic poles, which in turn become dragged along by the electromagnetic force from the rotating magnetic field in the stator.

6. GENERATOR OPERATION

Now, what happens if we manually crank this rotor around at exactly the synchronous speed of the generator, e.g. 1500 rpm (revolutions per minute), as we saw for the 4-pole synchronous generator on the previous page? The answer is: Nothing. Since the magnetic

field rotates at exactly the same speed as the rotor, we see no induction phenomena in the rotor, and it will not interact with the stator.

But what if we increase speed above 1500 rpm? In that case the rotor moves faster than the rotating magnetic field from the stator, which means that once again the stator induces a strong current in the rotor. The harder you crank the rotor, the more power will be transferred as an electromagnetic force to the stator, and in turn converted to electricity which is fed into the electrical grid.

7. GENERATOR SLIP

The speed of the asynchronous generator will vary with the turning force (moment, or torque) applied to it. In practice, the difference between the rotational speed at peak power and at idle is very small, about 1 per cent. This difference in per cent of the synchronous speed is called the generator's slip. Thus a 4-pole generator will run idle at 1500 rpm if it is attached to a grid with a 50 Hz current. If the generator is producing at its maximum power, it will be running at 1515 rpm.

It is a very useful mechanical property that the generator will increase or decrease its speed slightly if the torque varies. This means that there will be less tear and wear on the gearbox. (Lower peak torque). This is one of the most important reasons for using an asynchronous generator rather than a synchronous generator on a wind turbine which is directly connected to the electrical grid.

8. AUTOMATIC POLE ADJUSTMENT OF THE ROTOR

Did you notice that we did not specify the number of poles in the stator when we described the rotor? The clever thing about the cage rotor is that it adapts itself to the number of poles in the stator automatically. The same rotor can therefore be used with a wide variety of pole numbers.

9. GRID CONNECTION REQUIRD

On the page about the permanent magnet synchronous generator we showed that it could run as a generator without connection to the public grid. An asynchronous generator is different, because it requires the stator to be magnetized from the grid before it works. You can run an

asynchronous generator in a standalone system, however, if it is provided with capacitors which supply the necessary magnetization current. It also requires that there be some remanence in the rotor iron, i.e. some leftover magnetism when you start the turbine. Otherwise you will need a battery and power electronics, or a small diesel generator to start the system.

Table 1.1 GROSS POTENTIAL OF INDIA

S No.	States	Gross Potential
1	Andhra Pradesh	8275
2	Gujarat	9675
3	Karnataka	6620
4	Kerla	875
5	Madhya Pradesh	5500
6	Maharashtra	3650
7	Orissa	1700
8	Rajasthan	5400
9	Tamilnadu	3050
10	West Bengal	450
	Total	45,195

5.2 CALCULATIONS

Total no of machines	=	58
Total capacity	=	13.5 MW
Each machine capacity	=	225/40 KW
Minimum air velocity for the starting of wind turbine	=	2m/s

Induction Generator

Over 1000 rpm Induction generator generate	40 KW
Over 1500 rpm Induction generator generate	225 KW

Over 1650 rpm working must be stopped due to over speed fault

Height of windmill	**30 m**
Installation cost of per machine	1, 10, 00,000 Rs
Highest generation in a day	2, 02,900 KW
Date of highest generation	07/06/2003
Highest generation in a month	32,80,200kwh
Month of highest generation	May 2002

Total Generation:

Production = 2686829 KWh
Operating hours = 8429
Stopped hours = 12

Generator 1

Production = 22, 23,351 KWh
Operating hours = 3,414
Mode = 1,234 times
Speed = 1,500 rpm

Generator 2

Production = 4, 63,479 KWh
Operating hours = 3,607
Mode = 6,089 times
Speed = 1,000 rpm

Total hours in one year = 24 * 365 hours

IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 2 Issue 3, March 2015.

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ISSN 2348 – 7968

	= 8,760 hours
Operation time for generator 1(G1)	= 3,414 hours
Operation time for generator 2(G2)	= 3,607 hours
System fail time	= 12 hours
Time when grid is not available	= 76 hours in month
Total hours in one year	= 76 * 12 hours
	= 912 hours
Total Down time in a year	= 912+12 = 924 hours
Unavailability (FOR, q)	= 924/ 924+8429
	= 0.098 = 0.1
Availability (p)	= 8429/ 924+8429
	= 0.901 = 0.9

10. CALCULATION FOR EXACT CAPACITY STATES

When all units are available P(n) $= {}^{n}c_{r} * p^{n-r} * q^{r}$

Where

  n = Total number of units
  r = number of units out
  p = availability
  q = unavailability (FOR)

When all units are available then,
  n = 5 & r = 0

$$P(5) = {}^{5}c_{0} * 0.9^{(5-0)} * 0.1^{0}$$
$$= 0.59049$$

When one unit is out then
n = 5 & r = 1

$$P(4) = {}^{5}c_{1} * 0.9^{(5-1)} * 0.1^{1}$$
$$= 0.32805$$

When two units is out then
n = 5 & r = 2

$$P(3) = {}^{5}c_{2} * 0.9^{(5-2)} * 0.1^{2}$$
$$= 0.0729$$

When three units is out then
n = 5 & r = 3

IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 2 Issue 3, March 2015.

www.ijiset.com

ISSN 2348 – 7968

$$P(2) = {}^5c_3 * 0.9^{(5-3)} * 0.1^3$$
$$= 0.0081$$

When Four units are out then

n = 5 & r = 4

$$P(1) = {}^5c_4 * 0.9^{(5-4)} * 0.1^4$$
$$= 0.00045$$

When all units are out then

n = 5 & r =5

$$P(0) = {}^5c_5 * 0.9^{(5-5)} * 0.1^5$$
$$= 0.00001$$

10.1. CALCULATION FOR CUMULATIVE CAPACITY STATES:

A RECURSIVE ALGORITHM FOR CAPACITY MODEL BUILDING:

The capacity model can be created using a simple algorithm which can also be used to remove a unit from the model. This approach can also be used for a multi-state unit, i.e. a unit which can exist in one or more Derated or partial output states as well as in the fully up and fully down states.

Case-1 NO DERATED STATES

The cumulative probability of a particular capacity outage state of X MW after a unit of capacity C MW and forced outage rate U is added is given by

P(X) = (1-U) P'(X) + (U) P' (X-C)   Eq. A

Where P'(X) and P(X) denote the cumulative probabilities of the capacity outage state of X MW before and after the unit is added. The above expression is initialized by setting P'(X) = 1.0 for $X \leq$ 0 and P'(X) = 0 otherwise.

Case-2 DERATED STATES INCLUDED

Equation A can be modified as follows to include multi-state unit representations.

$$P(X) = \sum_{i=1}^{n} p_i P'(X - C_i)$$ Eq. B

where   n= number of unit states

C_i=capacity outage of state I for the unit being added

p_i =probability of existence of the unit state *i*

when   n=2, equation B reduces to equation A

now the system capacity outage probability is calculated sequentially as follows

Total Up time = 8429 Hrs.

Total down time = 924 Hrs.

A = 0.9

Hence

U = 0.1

Step-1 Add the first unit:

P(0)   = (1-0.1)1 + 0.1 P'(0-0) = 1

IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 2 Issue 3, March 2015.

www.ijiset.com

ISSN 2348 – 7968

P(225)   = (1-0.1)0 + 0.1P' (225-225) = 0.1

Step-2 Add the second unit:
      P(0)   = (1-0.1)1 + 0.1*1 = 1
      P(225)   = (1-0.1)0.1 + 0.1 P'(225-225) = 0.19
      P(450)   = (1-0.1)0 + 0.1 P'(450-225) = 0.01
Step-3 Add the Third unit:

      P(0)   = (1-0.1)1 + 0.1(1) = 1
      P(225)   =(1-0.1)0.19 + 0.1 P'(225-225) = 0.271
      P(450)   = (1-0.1)0.01 + 0.1 P'(450-225) = 0.028
      P(675)   = (1-0.1)0 + 0.1 P'(675-225) = 0.001

Step-4 Add the Fourth unit:

      P(0)   = (1-0.1)1 + 0.1(1) = 1
      P(225)   = (1-0.1)0.271 + 0.1(1) = 0.3439
      P(450)   = (1-0.1)0.028 + 0.1(0.271) = 0.0523
      P(675)   = (1-0.1)0.001 + 0.1 (0.028) = 0.0037
      P(900)   = (1-0.1)0 + 0.1 (0.001) = 0.0001

Step-5 Add the Fifth unit:

      P(0)   = (1-0.1)1.0 + 0.1(1) = 1
      P(225)   = (1-0.1)0.3439 + 0.1(1) = 0.40951
      P(450)   = (1-0.1)0.0523 + 0.1(0.3439) = 0.08146
      P(675)   = (1-0.1)0.0037 + 0.1(0.0523) = 0.00856
      P(900)   = (1-0.1)0.0001 + 0.1(0.0037) = 0.000461
      P(1125) = (1-0.1)0 + 0.1 (0.0001) = 0.00001

Step-6 Add the Sixth unit:

      P(0)   = (1-0.1)1 + 0.1(1) = 1
      P(225)   = (1-0.1)0.40951 + 0.1(1) = 0.468559
      P(450)   = (1-0.1)0.08146 + 0.1 (0.40951) = 0.114265
      P(675)   = (1-0.1)0.00856 + 0.1 (0.08146) = 0.01585
      P(900)   = (1-0.1)0.000461 + 0.1 (0.00856) = 0.0012709
      P(1125) = (1-0.1)0.00001 + 0.1(0.000461) = 0.0000551
      P(1350) = (1-0.1)0 + 0.1(0.00001) = 0.000001

Step-7 Add the Seventh unit:

      P(0)   =(1-0.1)1 + 0.1(1) = 1
      P(225)   = (1-0.1)0.468559 + 0.1(1) = 0.5217031
      P(450)   = (1-0.1)0.114265 + 0.1(0.468559) = 0.1496944
      P(675)   = (1-0.1)0.01585 + 0.1(0.114265) = 0.0256915
      P(900)   = (1-0.1)0.0012709 + 0.1(0.01585) = 0.00272881
      P(1125) = (1-0.1)0.0000551 + 0.1(0.0012709) = 0.00017668
      P(1350) = (1-0.1)0.000001 + 0.1(0.0000551) = 0.00000641
      P(1575) = (1-0.1)0 + 0.1(0.000001) = 0.0000001

Step-8 Add the Eighth unit:

$$P(0) = (1-0.1)1 + 0.1(1) = 1$$
$$P(225) = (1-0.1)0.5217031 + 0.1(1) = 0.5695$$
$$P(450) = (1-0.1)0.1496944 + 0.1(0.5217031) = 0.1869$$
$$P(675) = (1-0.1)0.0256915 + 0.1(0.1496944) = 0.03809$$
$$P(900) = (1-0.1)0.00272881 + 0.00256915 = 0.00502$$
$$P(1125) = (1-0.1)0.00017668 + 0.000272881 = 0.000432$$
$$P(1350) = (1-0.1)0.00000641 + 0.000017668 = 0.0000234$$
$$P(1575) = (1-0.1)0.0000001 + 0.00000641 = 0.0000065$$
$$P(1800) = (1-0.1)0 + 0.1(0.0000001) = 0.00000001$$

Step-9 Add the Ninth unit:

$$P(0) = (1-0.1)1.0 + 0.1(1) = 1$$
$$P(225) = (1-0.1)0.5695 + 0.1(1) = 0.6126$$
$$P(450) = (1-0.1)0.1869 + 0.1(5695) = 0.2252$$
$$P(675) = (1-0.1)0.03809 + 0.1(0.1869) = 0.05297$$
$$P(900) = (1-0.1)0.00502 + 0.1(0.03809) = 0.00833$$
$$P(1125) = (1-0.1)0.000432 + 0.1(0.00502) = 0.00045$$
$$P(1350) = (1-0.1)0.0000234 + 0.1(0.000432) = 0.000064$$
$$P(1575) = (1-0.1)0.0000065 + 0.1(0.0000243) = 0.0000082$$
$$P(1800) = (1-0.1)0.00000001 + 0.1(0.0000065) = 0.00000066$$
$$P(2025) = (1-0.1)0 + 0.1(0.00000001) = 0.000000001$$

Step-10 Add the Tenth unit:

$$P(0) = (1-0.1)1.0 + 0.1(1) = 1$$
$$P(225) = (1-0.1)0.6126 + 0.1(1) = 0.65134$$
$$P(450) = (1-0.1)0.2252 + 0.1(0.6126) = 0.26394$$
$$P(675) = (1-0.1)0.05297 + 0.1(0.2252) = 0.070193$$
$$P(900) = (1-0.1)0.00833 + 0.1(0.05297) = 0.012794$$
$$P(1125) = (1-0.1)0.00045 + 0.1(0.00833) = 0.001238$$
$$P(1350) = (1-0.1)0.000064 + 0.1(0.00045) = 0.0001026$$
$$P(1575) = (1-0.1)0.0000082 + 0.1(0.000064) = 0.00001378$$
$$P(1800) = (1-0.1)0.00000066 + 0.1(0.0000082) = 0.000001414$$
$$P(2025) = (1-0.1)0.000000001 + 0.1(0.00000066) = 0.000000066$$
$$P(2250) = (1-0.1)0 + 0.1(0.000000001) = 0.0000000001$$

Table 2 RESULT OF DEWAS WIND POWER PLANT EXACT CAPACITY STATE

S No.	Outage Capacities	Available Capacities	Probability
1	1125	000	0.00001

IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 2 Issue 3, March 2015.

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ISSN 2348 – 7968

2	900	225	0.00045
3	675	450	0.0081
4	450	675	0.0729
5	225	900	0.32805
6	000	1125	0.59049

Table 3 RESULTS OF CUMULATIVE CAPACITY STATES

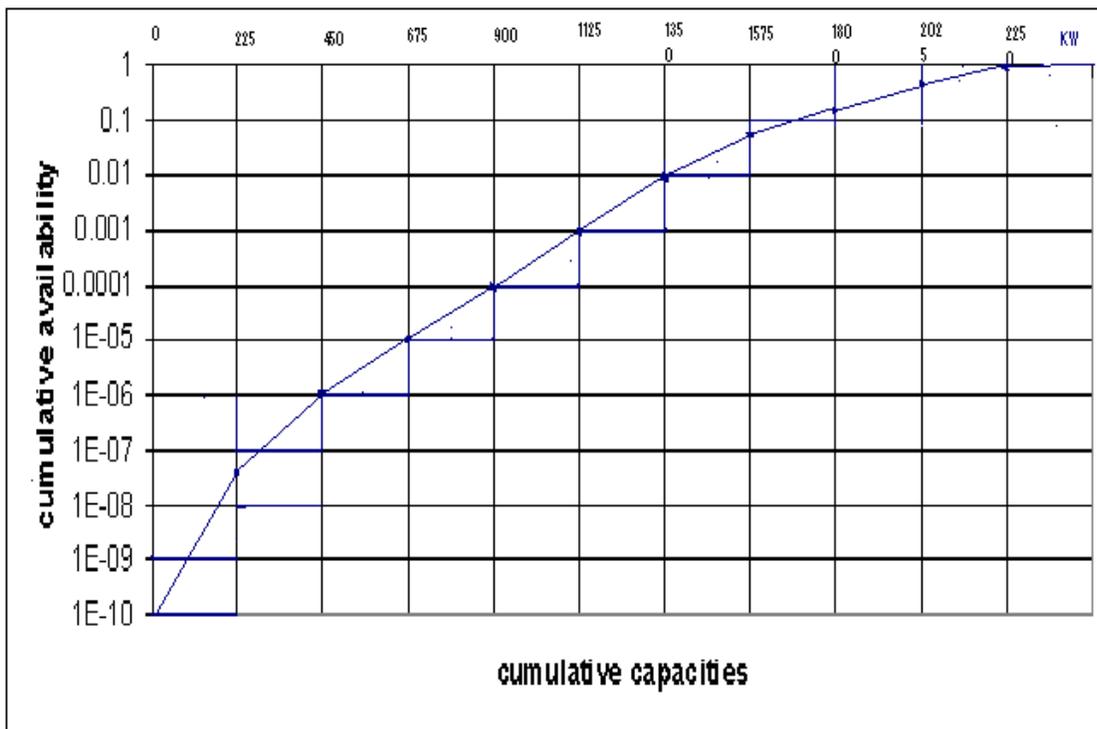| S No.	Cumulative outage capacities	Cumulative capacities	Cumulative probability
1	2250	0	0.0000000001
2	2025	225	0.000000066
3	1800	450	0.000001414
4	1575	675	0.00001378
5	1350	900	0.0001026
6	1125	1125	0.001238
7	900	1350	0.012794
8	675	1575	0.070193
9	450	1800	0.26394
10	225	2025	0.65134

cumulative capacities

255

Fig. 5.3.1 Cumulative capacity Vs cumulative availability

6.1 CONCLUSION

The case study of Dewas power plant Madhya Pradesh, India of 58 numbers of 225 KW each (13.5 MW).The reliability evaluation result of 10 units of Dewas plant connected to eastern grid were estimated. The estimates are based on the performance data of the respective units over a period of one year. As seen from the table in the beginning when all the units are in down state then the cumulative probability of availability is very low 0.0000000001 and when the all 10 units are available the cumulative probability of availability is 1. From each generating unit the probability of total generating capacity not exceeding a given power level was computed using analytical method. The results were shown in the form of graph. The graph is drawn between cumulative capacity state and cumulative available probability. From the graph the system availability from the given capacity is evaluated. This gives a measure of reliability of the system. The results presented give full insight into the generating capacities of each unit. These can be taken as a guide to arrive at the deficit of energy that can be expected. Thus the inevitable power cuts be planned in advance in rotational basis. The data also pinpoints the weaker aspects of the generating system, which requires strengthen. The data can also be used as a basis for reliability based expansion program of generating system, in order that future loads can be served effectively. From above study it is also observed that the wind speeds from November to March are low. This period is suitable for maintenance.

The power produced by the wind turbine increases from zero at the threshold wind speed (cut in speed) (usually around 5m/s but varies with site) to the maximum at the rated wind speed. Above the rated wind speed, (15 to 25 m/s) the wind turbine continues to produce the same rated power but at lower efficiency until shut down is initiated if the wind speed becomes dangerously high, i.e. above 25 to 30m/s (gale force). The exact specifications for energy capture by the turbine depend on the distribution of wind speed

over the year at the individual site. Air density has a significant effect on wind turbine performance. The power available in the wind is directly proportional to air density. As air density increases the available power also increases. Air density is a function of air pressure and temperature. It increases when air pressure increases or the temperature decreases. Both temperature and pressure decrease with increasing elevation. Consequently changes in elevation produce a profound effect on the generated power as a result of changing in the air density.

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