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Survey and Performance Evaluation of Jamgodrani Hills and Nagda Hill Wind Farm in Madhya Pradesh, India – A Case Study

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Abstract:

Today, most of the electricity generated comes from fossil fuels (coal, oil, and natural gas). These fossil fuels have finite reserves and will run out in the future. The negative effect of these fossil fuels is that they produce pollutant gases when they are burned in the process to generate electricity. Fossil fuels are a non-renewable energy source. However, renewable energy resources (solar, wind, hydro, biomass, geothermal and ocean) are constantly replaced, hence will not run out, and are usually less polluting. Due to an increase in greenhouse gas emissions more attention is being given to renewable energy. As wind is a renewable energy it is a clean and abundant resource that can produce electricity with virtually no pollutant gas emission. Induction generators are widely used for wind powered electric generation, especially in remote and isolated areas, because they do not need an external power supply to produce the excitation magnetic field. Furthermore, induction generators have more advantages such as cost, reduced maintenance, rugged and simple construction, brushless rotor (squirrel cage) and so on. This paper presents the detailed survey on performance of wind farms situated at Jamgodrani hills and Nagda hill, near Dewas city in Madhya Pradesh, India. Variation of various performance indices such as total yearly generation, total availability of grid, total availability of wind generator, total generating units per wind generator and capacity utilization factor is discussed for wind farm on Jamgodrani hills and Nagda hill respectively.Latter, it introduces a simple and direct formula based on complex impedance matrix method to calculate the minimum excitation capacitance (C_{min}) and corresponding maximum frequency (f_{max})required for successful voltage build up across the terminal of three phase dual winding induction generator when operating on 225kW rating, used as wind generator in wind farm and variation of minimum excitation capacitance as well as corresponding maximum frequency is also being plotted for various conditions of load and speed.

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Keywords: Renewable Energy; Wind Energy; Self-Excited Induction Generator (SEIG); Matlab/ Simulin; Total Harmonic Distortion (THD).

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1. Wind Farm: Case Study

In this section of our case study, we plotted the variation of various performance indices (fig. 3 to fig. 11) of wind farm situated at Jamgodrani Hills and Nagda hill (shown in fig.1 & fig.2), near Dewas city, Madhya Pradesh. The data for plotting the yearly variation of various performance indices is shown in table 1 and table2. These performance indices actually represent the performance of wind generator annually. In terms of capacity factor, Wind power plants differ in a variety of ways from power plants that burn fuel. In spite of the downtime in a year, a coal plant can be run day and night at almost its rated capacity during any season of the year. In contrast, that wind speed varies with the time of the day and with the season.

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Fig. 1 Wind farm at Jamgodrani hills near Dewas City (M.P)

Fig. 2 Power factor correction capacitor for wind generator

Table 1 Performance Indices of wind farm at Nagda hill, 15.00 MW (25 × 0.600 MW)

Year	Annual average generation per wind electric generator (lac-units)	% capacity utilization factor	Annual average % grid availability	Annual average % wind generator availability
2008-09	9.55	18.38	98.69	99.81
2009-10	9.19	17.55	99.32	99.24
2010-11	8.56	16.18	99.09	99.28
2011-12	8.31	15.93	99.08	97.33

Table 2 Performance Indices of wind farm at Jamgodrani hills, 13.05 MW (58× 0.225 MW)

Year	Annual average generation per wind electric generator (lac-units)	% capacity utilization factor	Annual average % grid availability	Annual average % wind generator availability
2002-03	2.68	13.59	94.74	95.56
2003-04	2.16	10.97	98.25	95.36
2004-05	2.45	12.46	98.51	93.65
2005-06	1.99	10.13	99.05	96.54
2006-07	2.32	11.79	98.72	96.16
2007-08	1.95	9.92	97.86	93.62
2008-09	1.86	9.43	96.49	88.53
2009-10	1.96	9.94	96.98	93.36
2010-11	1.76	8.91	97.60	88.75
2011-12	1.74	8.84	96.97	88.61

At times the wind speed may even be insufficient to drive the turbine. Consequently, a wind turbine cannot operate 24 hours a day, 365 days a year at full power. A wind farm generally runs 65-80% of the time in a year with variation in output power. Because wind farms get paid for the total energy production, the annual energy output is a more relevant measure for evaluating a wind turbine that it's rated power at certain speed. In terms of percent availability of machine, one refers that availability of any particular wind farm is low for short-term operation. For any individual generator there is an 80% coincidental that wind output will change less than 10% in an hour and a 40% chance that it will change 10% or more in 5 hours. However, studies propose that, in practice, the deviations in thousands of wind turbines, blow-out out over numerous diverse sites and wind systems, are flattened. As the distance between sites increases, the correspondence between wind speeds restrained at those sites, drops. Thus, while the output from a single turbine can vary significantly and quickly as local wind speeds vary, as additional turbines are associated above bigger and larger areas the ordinary power output becomes less mutable and more expectable. Wind speeds can be correctly estimated over large areas, and hence wind is a anticipated source of power for nurturing into an electrical grid. However, due to the inconsistency, although predictable, wind energy accessibility must be schedule.

In terms of percent availability of grid, we analyze that many wind farms are connected to the local network, medium or high voltage. The injection of wind power into the network has an impact on the voltage magnitude, its flicker, and its waveform at the point of common coupling (PCC). The effect on the voltage magnitude of the grid depends on the strength of the utility distribution network at the point of the wind generator(s). The strength of the system at the point of coupling under consideration is decided by the short-circuit power, called the fault level, at that point. The shot circuited power is the product of the short-circuit current, following a three-phase fault at that point, and the voltages of the system.

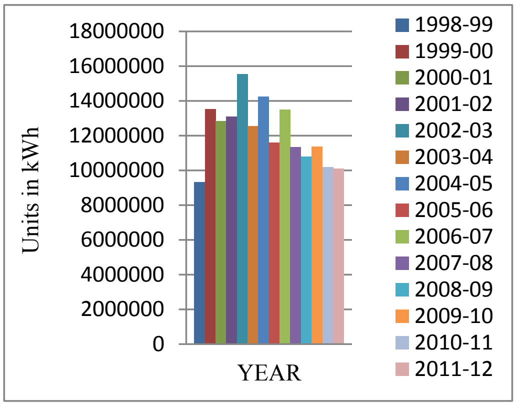

Fig. 3 Total yearly generation on Jamgodrani hills

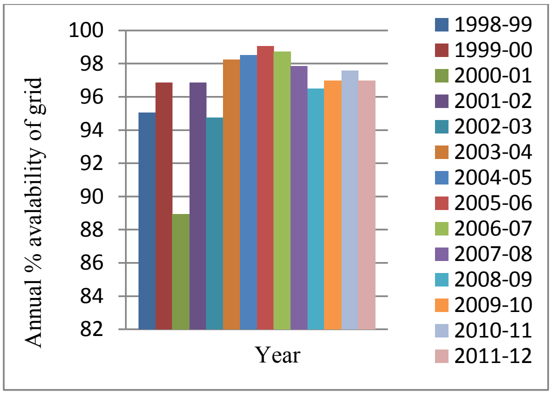

Fig. 4 Total availability of grid at Jamgodrani hills

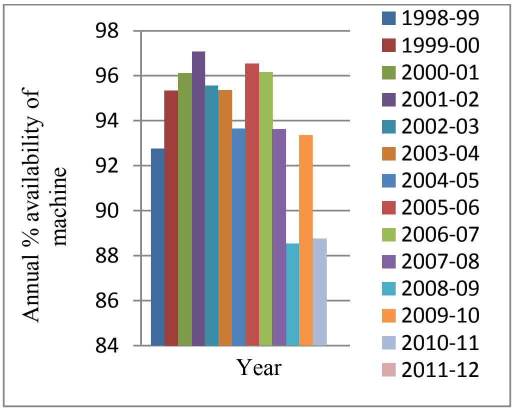

Fig. 5 Total availability of wind generator at Jamgodrani hill

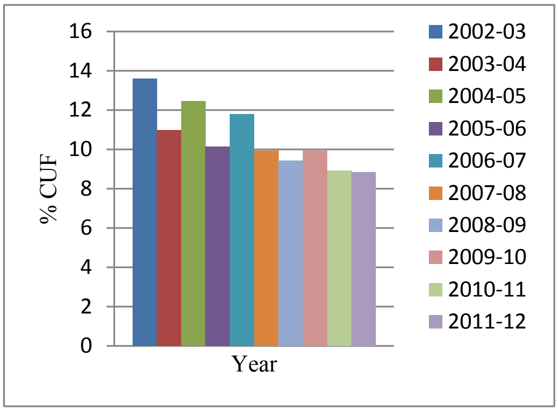

Fig. 6 Yearly variation of capacity utilization factor of wind farm at Jamgodrani hills

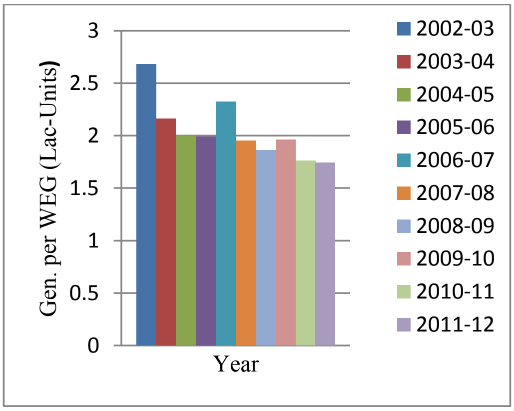

Fig. 7 Annual average generations per wind electric generator (Lac-Units) at Jamgodrani hills

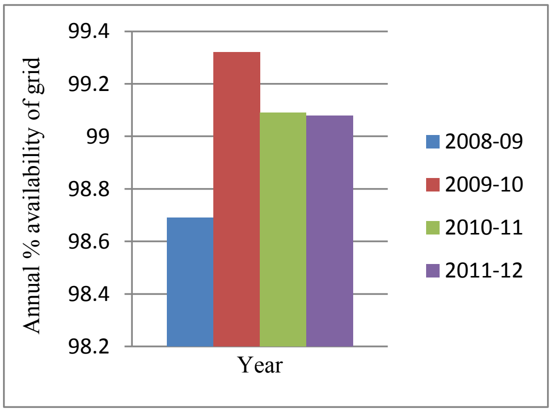

Fig. 8 Total availability of grid at Nagda hill

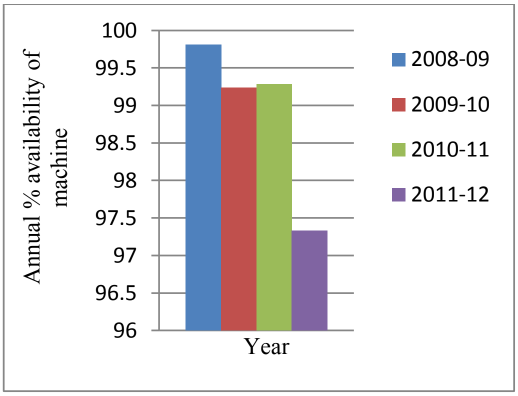

Fig. 9 Total availability of wind generator at Nagda hill

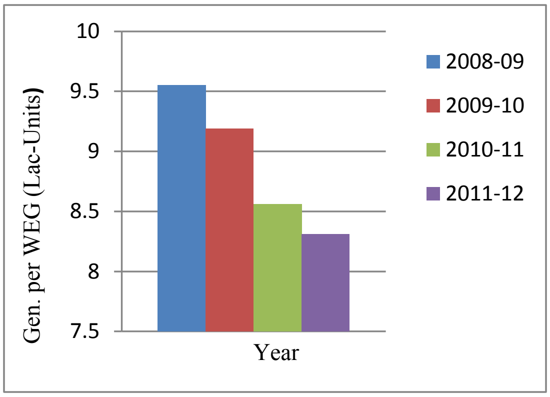

Fig. 10 Annual average generations per wind electric generator (Lac-Units) at Nagda hill

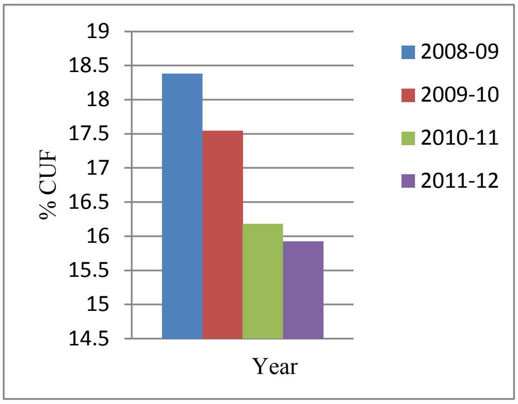

Fig. 11 Yearly variation of capacity utilization factor of wind farm at Nagda hill

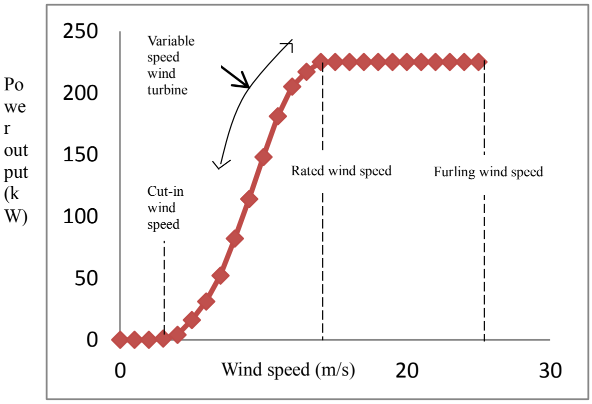

Fig. 12 Power curve of VESTAS V27-225 kW wind turbine

2. Calculation of $C_{\min}$ by Complex Impedance Matrix Method for Wind Generator

When an inductive load (R-L) is connected across the terminal of three phase self-excited induction generator (SEIG), the dynamic equations in the complex differential form with flux linkages as state variables in the arbitrary reference frame is given [5] and [6], where 's' denotes the stator and 'r' is for rotor:-

$$\begin{bmatrix} p\lambda_{qds} \\ p\lambda_{qdr} \\ pv_{qds} \\ pi_{lqd} \end{bmatrix} = \begin{bmatrix} T_s + j\omega & B_s & 1 & 0 \\ B_r & T_r + js & 0 & 0 \\ \dfrac{T_{ss}}{C} & -\dfrac{B_{ss}}{C} & j\omega & -\dfrac{1}{C} \\ 0 & 0 & {}^{1}/_{X_L} & -\dfrac{R_L}{X_L} + j\omega \end{bmatrix} \begin{bmatrix} \lambda_{qds} \\ \lambda_{qdr} \\ v_{qds} \\ \nu_{lqd} \end{bmatrix} \tag{1}$$

Where,

$T_{ss} = -R_s X_{rr}/D, T_r = -R_r X_{ss}/D, T_{ss} = -X_{rr}/D$

$B_s = R_s X_{mu}/D, B_r = R_r X_{mu}/D, B_{ss} = -X_{mu}/D$

$D = X_{ss}X_{rr} - X_{mu}^2, X_{ss} = X_s + X_{mu}$, and $X_{rr} = X_r + X_{mu}$

For balanced steady state condition, the variables in d-q reference frames are sinusoidal quantities in all asynchronously rotating frames except the fact that in synchronously rotating frames they are constants[7]. Hence, in all synchronously rotating frames of references$'\omega'$ is the angular frequency of the self-exciting voltages and currents,

Also steady state value of voltages and current can be obtained by putting time derivative of state variables equal to zero (p=0) in equation (1).

On putting determinant of the complex impedance matrix equal to zero, we got the following expression:

$$(T_s + j\omega)\{(T_r + js)(j\omega(j\omega - R_L/X_L) + 1/X_L C)\} - B_s B_r (j\omega(j\omega - R_L/X_L) + 1/X_L C) - B_r B_{ss}(j\omega - R_L/X_L)/C - (T_r + Js)(j\omega - R_L/X_L)\, T_{ss}/C) = 0 \tag{2}$$

On equating real part of equation (2), we get equation (3)

$$C\{s(R_L T_s \omega + X_L \omega^3) + \omega^2 (B_r B_s X_L + T_r R_L - T_s T_r X_L)\} = s\omega(1 - T_{ss} X_L) + B_r (B_s - R_L B_{ss}) \; - T_r (T_s + R_L T_{ss}) \tag{3}$$

On rearranging the above equation, we get

$$C = \frac{c_1 s + c_0}{d_1 s + d_0} \tag{4}$$

Equating imaginary part equal to zero of equation (2), we get equation (5)

$$s\{R_L T_{ss} + T_s) + C\omega(R_L - T_s X_L)\} - C\omega(T_r T_s R_L + T_r X_L \omega^2 - B_r B_s R_L) - \omega(B_r B_{ss} X_L + T_r T_{ss} X_L - T_r) = 0 \tag{5}$$

On substituting the value of ‘*C’* from equation (4) into equation (5), one can get the following second order equation is angular slip frequency‘s’*:*

$$x_2 s^2 + x_1 s + x_0 = 0 \tag{6}$$

On solving equation (6), we got:-

$$s = -\frac{x_1}{2x_2} + \sqrt{\left(\frac{x_1}{2x_2}\right)^2 - \left(\frac{x_0}{x_2}\right)} \tag{7}$$

Since‘s’ is small negative quantity in case of SEIG. Therefore only positive sign is considered.

Hence, self-excitation frequency is given by:

$$\omega = \omega_r - \frac{x_1}{2x_2} + \sqrt{\left(\frac{x_1}{2x_2}\right)^2 - \left(\frac{x_0}{x_2}\right)} \tag{8}$$

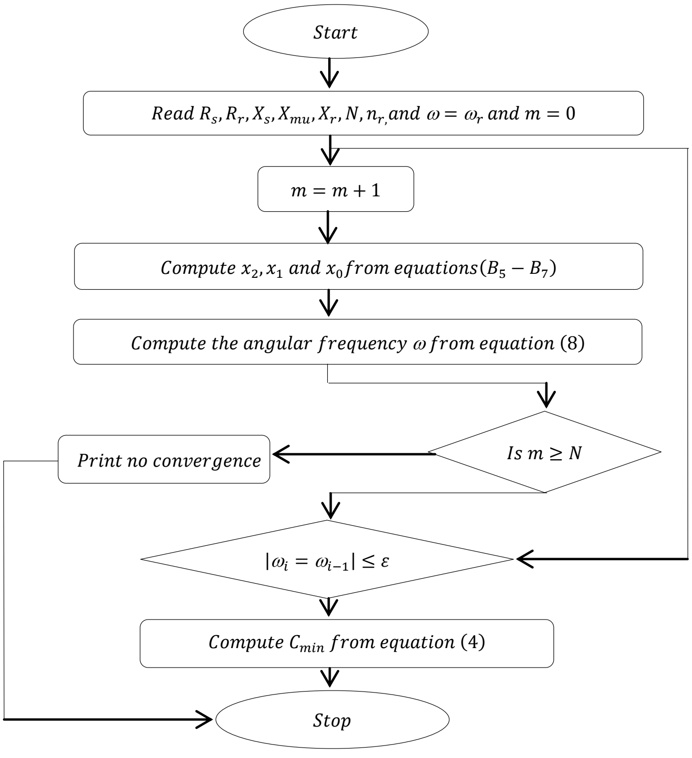

Fig. 13 Flow chart for computation of C_{min}

Fig. 13 shows the flow chart for the computer computation of the minimum self-excitation capacitance of self-excited induction generator based on complex impedance matrix method.

a) Read the machine data (R_s, R_r, X_r, X_s), prime mover speed, p.f. 0f load, synchronous speed test data etc.

b) Assume an initial value of angular frequency ω and take the value of $\omega = \omega_r$.

c) Evaluate x_2, x_1 and x_0 are calculated from (B_5-B_7).

d) The value of the angular frequency ω is updated using equation (8).

e) Repeat steps (a) and (b), each time using the updated value of ω for evaluating $x_2,$ x_1 and x_0 until the values of ω in two successive iterations satisfy a specific accuracy.

f) By getting the value of angular frequency, the value of C_{min} is computed directly from equation (4).

3. Results and Discussions

The proposed method (4) of determining the minimum excitation capacitance is tested on a wind generator used in our case study as shown in Table 3.

Table 3 Wind Turbine Specifications Installed for Case Study

Generator	
Rated power output	225 kW/40 kW
Type	Dual wound asynchronous
Voltage	440 V/ 3 phase
Revolutions	1500/1000 rpm
Frequency	50
Total number of wind turbines	58
Gear-box	
Type	Two stage, parallel shafts
Gear ratio	1:40
Number of steps	2
Tower	
Type	Tubular
Height	30 m/ 34 m
Material	steel
Rotor	
Type	Squirrel cage
Number of blades	3
Diameter	3.4 m
Stator	
Pole	4/6
Winding	Uniformly distributed
Stator resistance per phase	0.019 Ω
Stator reactance X_1 per phase	0.18 Ω
Rotor	
Rotor resistance per phase	0.019 Ω
Rotor reactance X_2 per phase	0.345 Ω
Magnetizing reactance X_m	4.8 Ω
Overall data	
Cut in wind speed	3.0 m/s
Cut out wind speed	14 m/s
Survival wind speed	25 m/s
Rotor speed	1500 rpm@225 kw& 1000rpm@40 kw

The induction generator specifications in terms of per unit values are: $R_s = 0.010955\,p.u$, $X_s = 0.1042\,p.u$, $R_r = 0.010955\,p.u$, $X_r = 0.19965\,p.u$, $X_m = 2.77\,p.u$, $b = 1\,p.u$, $f_b = 50\,Hz$, $Z_b = 1.728\,p.u$, $N = 1500\,rpm$

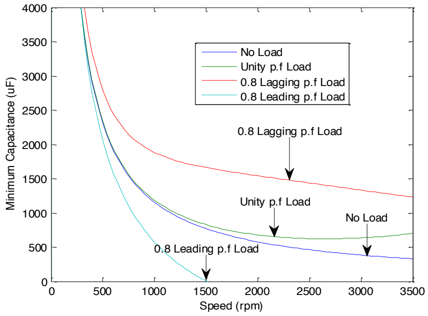

Fig. 14 (a) Variation of minimum capacitance (μf) withspeed (rpm) for (R-L) load

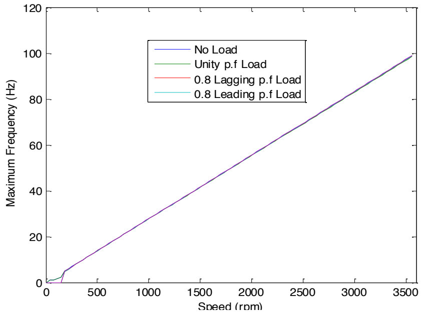

Fig. 14(b) corresponding change in maximum frequency (Hz) for (R-L) load

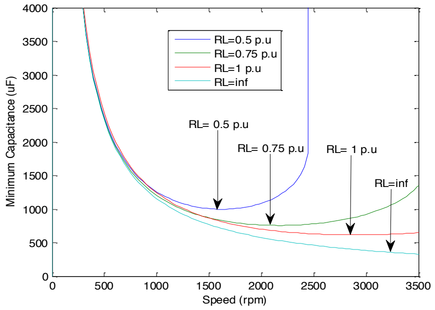

Fig. 15(a) Variation of minimum capacitance (μf) with speed (rpm) for purely resistive load

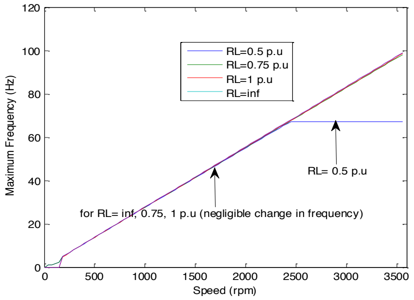

Fig. 15(b) corresponding change in maximum frequency (Hz) for purely resistive load

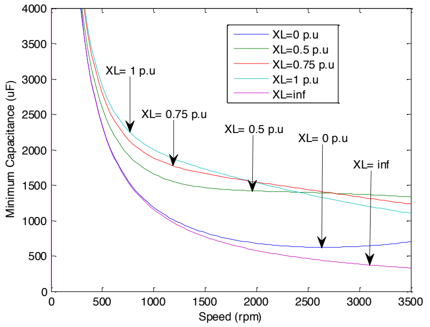

Fig. 16 (a) Variation of minimum capacitance (μf) with speed (rpm) at RL= 1 p.u

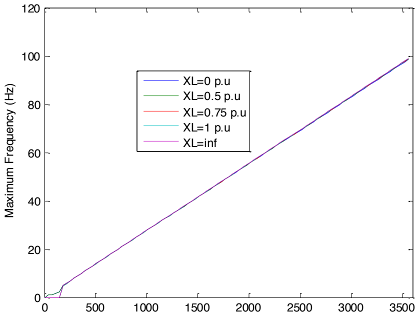

Fig. 16(b) corresponding change in maximum frequency (Hz) for RL= 1 p.u

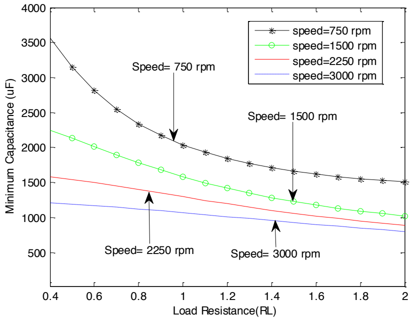

Fig. 17 Variation of minimum capacitance (μf) with load resistance (RLΩ) at XL=1 p.u.

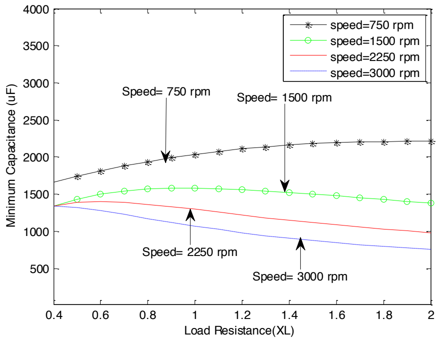

Fig. 18 Variation of minimum capacitance (μf) with load reactance (XL Ω) at RL=1 p.u.

4. Conclusions

In this paper a detailed study of various performance indices necessary to determine the reliability and performance of a particular wind farm i.e. wind farm situated at Jamgodrani hills and Nagda hill is presented as a case study. Latter, it introduces the complex impedance matrix method to calculate minimum excitation capacitance (C_{min}) required for successful voltage buildup across the terminal of three phase SEIG used as wind generator in our case study. The study of performance indices is very essential, as it determines the reliability and site matching of wind generator for a particular wind farm. Also a simple and direct formula based on complex impedance matrix method is also being used to determine the variation in minimum excitation capacitance (C_{min}) and corresponding maximum frequency (f_{max}) for different operating conditions of load and speed. the results obtained from complex impedance matrix are verified by theoretical results.

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