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- The major challenge in wind energy production is the cost reduction.
- The cost of wind energy depends on various factors like:
  - location selection
  - farm layout design, predictive maintenance etc.
- Among these factors farm layout design is import because an inadequate layout design leads to lower power capture than the expected and leads to increased maintenance cost or so on.

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  2) Each wind turbine location is represented as two dimensional vector (x_i, y_i), $i = 1, 2, \ldots, M$ where M is number of turbines.
  3) Turbines in the farm are considered to be homogeneous .i.e. have similar design, brand, model, power curve, capacity etc.

Problem Statement and Modelling

4) At a given location and height wind speed μ follows the Weibull Distribution

$$p_\mu(\mu, \kappa, c) = \frac{\kappa}{c}\left(\frac{\mu}{c}\right)^{(\kappa-1)} e^{-\left(\frac{\mu}{c}\right)^{\kappa}}$$

where, p_μ is probability density function, c is scalar parameter and κ is shape parameter.

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5) Proper spacing between turbines reduces the wind turbulence effect. Thus, spacing between the turbines should be proper.So, turbines locations should satisfy the inequality

$$(x_i - x_j)^2 + (y_i - y_j)^2 \geq 64R^2, \quad i \neq j$$

where, R is rotor radius.

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where, R is rotor radius.

6) All turbines must be situated within the farm.All the turbines must satisfy the constraint

$$x_i^2 + y_i^2 \leq r^2$$

Wake Effect Model

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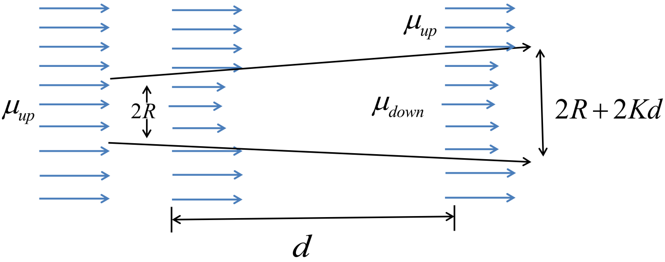
- Wake loss is the major factor in the wind park layout design.
- A linear expanding wake appears behind the turbine, when a uniform wind encounters a wind turbine.



$$vel\_def_{ij} = 1 - \frac{\mu_{down}}{\mu_{up}} = \frac{1-\sqrt{1-C_r}}{(1+Kd_{ij}/R)^2}$$

Optimization Problem

- The mathematical model of wind farm layout optimization problem is:

$$
\begin{aligned}
&\max \sum_{i=1}^{M} E(P_i) \\
&\text{s.t.} \\
&(x_i - x_j)^2 + (y_i - y_j)^2 \geq 64R^2 \quad i = 1, 2, \ldots, M, i \neq j \\
&x_i^2 + y_j^2 \leq r^2
\end{aligned}
$$

where, $E(P_i)$ is the power output of i^{th} turbine.

Optimization Problem

$$E(P_i) = \alpha \sum_{j=1}^{M_\mu+1} \left(\frac{\mu_{j-1}+\mu_j}{2}\right) \sum_{t=1}^{M_\phi+1} \Bigg[(\phi_t - \phi_{t-1}) \left\{ e^{-\left(\mu_{j-1}/c_i\left(\frac{\phi_t+\phi_{t-1}}{2}\right)\right)^{\kappa\left(\frac{\phi_t+\phi_{t-1}}{2}\right)}} - e^{-\left(\mu_j/c_i\left(\frac{\phi_t+\phi_{t-1}}{2}\right)\right)^{\kappa\left(\frac{\phi_t+\phi_{t-1}}{2}\right)}} \right\} \Bigg]$$

$$+ P_{rated} \sum_{t=1}^{M_\phi+1} (\phi_t - \phi_{t-1}) \omega_{t-1} e^{-\left(\mu_{rated}/c_i\left(\frac{\phi_t+\phi_{t-1}}{2}\right)\right)^{\kappa\left(\frac{\phi_t+\phi_{t-1}}{2}\right)}}$$

$$+ \beta \sum_{t=1}^{M_\phi+1} \Bigg[(\phi_t - \phi_{t-1}) \omega_{t-1} \left\{ e^{-\left(\mu_{cut\_in}/c_i\left(\frac{\phi_t+\phi_{t-1}}{2}\right)\right)^{\kappa\left(\frac{\phi_t+\phi_{t-1}}{2}\right)}} - e^{-\left(\mu_{rated}/c_i\left(\frac{\phi_t+\phi_{t-1}}{2}\right)\right)^{\kappa\left(\frac{\phi_t+\phi_{t-1}}{2}\right)}} \right\} \Bigg]$$

Genetic Algorithm

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- Genetic algorithm has mainly four components:
  - Selection
  - Crossover
  - Mutation
  - Elitism.

Selection and Crossover

- In selection process the fittest chromosome/solutions are selected to participate in matting pool.

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- Crossover operator combines the information of two parent solution randomly taken form the matting pool and generates child solutions
- **Simulated binary crossover(SBX) [1]:** Let P1 and P2 are two parent solutions randomly selected from the matting pool:

$$C_1 = 0.5(P_1 + P_2) - 0.5\eta(P_2 - P_1)$$
$$C_2 = 0.5(P_1 + P_2) + 0.5\eta(P_2 - P_1)$$

where, $P_2 > P_1$ and

$$\eta = \begin{cases} (2u)^{\left(\frac{1}{N_c+1}\right)}, & \text{if } \gamma \leq 0.5 \\ \left(\frac{1}{2(1-u)}\right)^{\left(\frac{1}{N_c+1}\right)}, & \text{if } \gamma > 0.5 \end{cases}$$

Scaling the Heights Indian Instit

Mutation and Elitism

- Mutation operator used to maintain genetic diversity from one generation of a population to the next generation.

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- Polynomial mutation is defined as follow [1]:

$$C' = \begin{cases} C + \delta_1(C - \bar{X}^L), & \text{if } rand() \leq 0.5 \\ C + \delta_2(\bar{X}^U - C), & \text{if } rand() > 0.5 \end{cases}$$

$rand() \in U[0,1]$

$$\begin{cases} \delta_1 = (2u)^{\left(\frac{1}{N_m+1}\right)} - 1, & \text{if } rand() \leq 0.5 \\ \delta_2 = 1 - (2(1-u))^{\left(\frac{1}{N_m+1}\right)}, & \text{if } rand() > 0.5 \end{cases}$$

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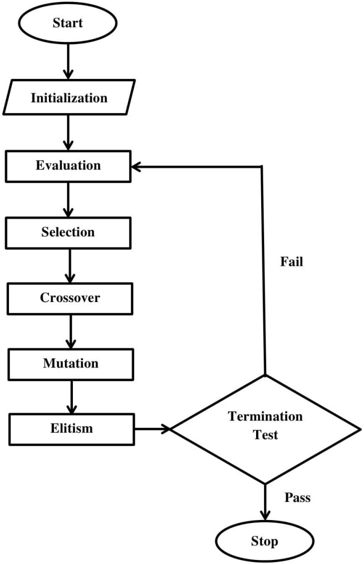
- Elitism is a process of keeping the some proportion of elite solutions(i.e. fittest solutions) of previous generation in the next generation.

Flow Chart of GA



Experimental Results:

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t-1	ϕ_{t-1}	ϕ_t	κ	c	ω_{t-1}
0	0	15	2	13	0
1	15	30	2	13	0.01
2	30	45	2	13	0.01
3	45	60	2	13	0.01
4	60	75	2	13	0.01
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- Population size, $N = 60$

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- Population size, $N = 60$
- Tournament size $= 3$

Experimental Results:

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0	0	15	2	13	0
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- Population size, $N = 60$
- Tournament size $= 3$
- Crossover probability, $C_p = 0.8$

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0	0	15	2	13	0
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- Population size, $N = 60$
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- Crossover probability, $C_p = 0.8$
- Mutation probability, $M_p = 0.1$

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- Crossover probability, $C_p = 0.8$
- Mutation probability, $M_p = 0.1$
- Elitism size $= 2$

Experimental Results:

t-1	ϕ_{t-1}	ϕ_t	κ	c	ω_{t-1}
0	0	15	2	13	0
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- Crossover probability, $C_p = 0.8$
- Mutation probability, $M_p = 0.1$
- Elitism size $= 2$
- Maximum generations $= 100$

Experimental Results:

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- Tournament size $= 3$
- Crossover probability, $C_p = 0.8$
- Mutation probability, $M_p = 0.1$
- Elitism size $= 2$
- Maximum generations $= 100$
- Farm radius, r $=$ 500m

Experimental Results:

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- Tournament size $= 3$
- Crossover probability, $C_p = 0.8$
- Mutation probability, $M_p = 0.1$
- Elitism size $= 2$
- Maximum generations $= 100$
- Farm radius, r $= 500$m
- Rotor radius, R $= 38.5$(m)

Experimental Results:

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0	0	15	2	13	0
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6	90	105	2	13	0.6
7	105	120	2	13	0.01
8	120	135	2	13	0.01
9	135	150	2	13	0.01
10	150	165	2	13	0.01
11	165	180	2	13	0.01
12	180	195	2	13	0.01
13	195	210	2	13	0.01
14	210	225	2	13	0.01
15	225	240	2	13	0.01
16	240	255	2	13	0.01
17	255	270	2	13	0.01
18	270	285	2	13	0.01
19	285	300	2	13	0.01
20	300	315	2	13	0.01
21	315	330	2	13	0.01
22	330	345	2	13	0.01
23	345	360	2	13	0

- Population size, $N = 60$
- Tournament size = 3
- Crossover probability, $C_p = 0.8$
- Mutation probability, $M_p = 0.1$
- Elitism size = 2
- Maximum generations = 100
- Farm radius, r = 500m
- Rotor radius, R = 38.5(m)
- Wind cut-in speed, $\mu_{cut\_in} = 3.5\ m/s$

Experimental Results:

t-1	ϕ_{t-1}	ϕ_t	κ	c	ω_{t-1}
0	0	15	2	13	0
1	15	30	2	13	0.01
2	30	45	2	13	0.01
3	45	60	2	13	0.01
4	60	75	2	13	0.01
5	75	90	2	13	0.2
6	90	105	2	13	0.6
7	105	120	2	13	0.01
8	120	135	2	13	0.01
9	135	150	2	13	0.01
10	150	165	2	13	0.01
11	165	180	2	13	0.01
12	180	195	2	13	0.01
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- Crossover probability, $C_p = 0.8$
- Mutation probability, $M_p = 0.1$
- Elitism size = 2
- Maximum generations = 100
- Farm radius, r = 500m
- Rotor radius, R = 38.5(m)
- Wind cut-in speed, $\mu_{cut\_in} = 3.5\ m/s$
- Wind rated speed, $\mu_{rated} = 14\ m/s$

Experimental Results:

t-1	ϕ_{t-1}	ϕ_t	κ	c	ω_{t-1}
0	0	15	2	13	0
1	15	30	2	13	0.01
2	30	45	2	13	0.01
3	45	60	2	13	0.01
4	60	75	2	13	0.01
5	75	90	2	13	0.2
6	90	105	2	13	0.6
7	105	120	2	13	0.01
8	120	135	2	13	0.01
9	135	150	2	13	0.01
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- Elitism size = 2
- Maximum generations = 100
- Farm radius, r = 500m
- Rotor radius, R = 38.5(m)
- Wind cut-in speed, $\mu_{cut\_in} = 3.5\ m/s$
- Wind rated speed, $\mu_{rated} = 14\ m/s$
- Rated power for rated wind speed, $P_{rated} = 1500\ kW$

Experimental Results:

t-1	ϕ_{t-1}	ϕ_t	κ	c	ω_{t-1}
0	0	15	2	13	0
1	15	30	2	13	0.01
2	30	45	2	13	0.01
3	45	60	2	13	0.01
4	60	75	2	13	0.01
5	75	90	2	13	0.2
6	90	105	2	13	0.6
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22	330	345	2	13	0.01
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- Farm radius, r = 500m
- Rotor radius, R = 38.5(m)
- Wind cut-in speed, $\mu_{cut\_in} = 3.5\ m/s$
- Wind rated speed, $\mu_{rated} = 14\ m/s$
- Rated power for rated wind speed, $P_{rated} = 1500\ kW$
- $\alpha = 140.86$, $\beta = -500$

Experimental Results:

Number of turbines	Ideal Power	BBO(best)/Wake loss[2]	GA(best)/Wake loss
2	14631.37	28091.47/0.0	28091.47/0.0
3	21947.06	21947.06/0.0	21947.06/0.0
4	29262.75	29262.75/0.0	29262.75/0.0
5	36578.44	36578.44/0.0	36522.05/56.3867
6	43894.12	43894.12/0.0	43854.78/39.34

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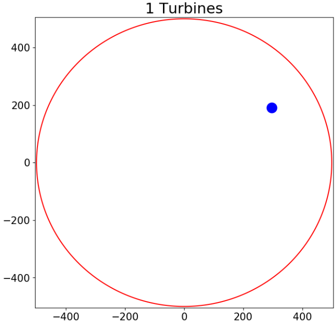
5	36578.44	36578.44/0.0	36522.05/56.3867
6	43894.12	43894.12/0.0	43854.78/39.34



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Experimental Results:

Number of turbines	Ideal Power	BBO(best)/Wake loss[2]	GA(best)/Wake loss
2	14631.37	28091.47/0.0	28091.47/0.0
3	21947.06	21947.06/0.0	21947.06/0.0
4	29262.75	29262.75/0.0	29262.75/0.0
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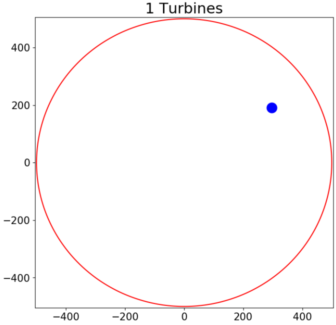

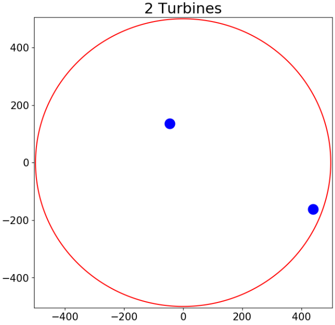

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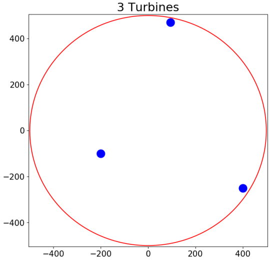
Experimental Results:



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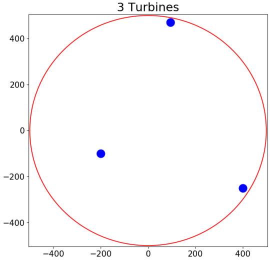

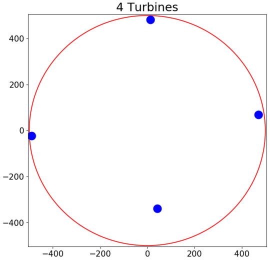

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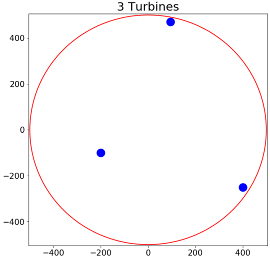

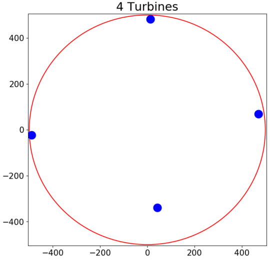

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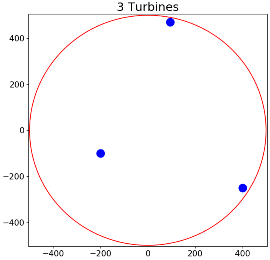

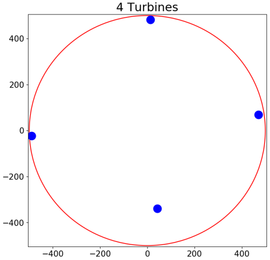

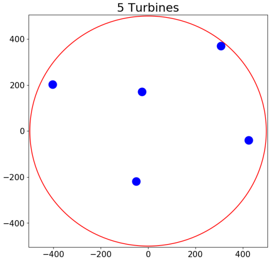

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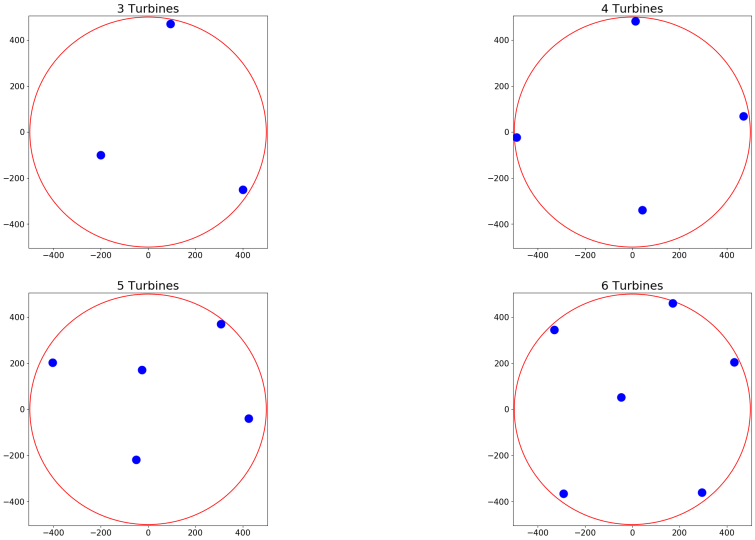

References

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Thank you