Security Constraint Unit Commitment on Combined Solar Thermal Generating Units using ABC Algorithm

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Abstract- In this paper, Security Constrained Unit Commitment (SCUC) problem with combined Thermal- Solar generating units is solved using Artificial Bee Colony (ABC) algorithm. SCUC problem aims to obtain minimum generation cost while satisfying the system, network and security constraints. The SCUC problem is divided into Unit Commitment Problem (UCP) which is considered as the master problem and Security Constrained Economic Dispatch (SCED) is considered as the sub problem. Here, both thermal and solar generations are considered in UCP and SCED solutions. Binary Coded ABC Algorithm is used to solve the UCP and Real Coded ABC Algorithm is used for solving the SCED problem. The constraints such as spinning reserves, hourly load demands, ramp up/ramp down limits of generators, minimum up/down limits, line flow and voltage limits are considered in the problem formulation. Beta distribution function is employed to forecast the solar power generation in different seasons. The comparison is carried out with and without incorporating solar generation. The proposed method is validated on a 6 bus system and a South Indian 86 bus utility.

Keywords Solar farm; Security Constraints; Unit Commitment ; Beta distribution function; ABC Algorithm.

1. Introduction

Unit Commitment (UC) is a significant scheduling problem for the economic and steady operation of the power system. It aims in finding an optimum schedule to commit the generators to meet the forecasted load demand, while minimizing the generation cost. This is obtained while satisfying the unit and system constraints. This is done in such a way that, the cheap generators are always committed and the expensive generators are committed whenever required, such that the cost is minimum. [1]. At certain situations when the real time condition diverges from the expected one, the operator should commit expensive fast start generators to maintain system security. While doing the dispatch, care is taken such that the power flow limits of the lines are not exceeded and the bus voltages are within their limits. When these security constraints are imposed then the traditional UC is called as Security Constrained Unit Commitment (SCUC) [2-4].

SCUC is a complex problem and numerous techniques have been applied to solve this effectively. SCUC problem is solved by Lagrangian Relaxation (LR) [5] which has the drawback of perverse relaxations for discrete variables. Benders decomposition technique [6,7], Genetic Algorithm [8], Dantzig– Wolfe method [9] are used for solving SCUC. In [10] SCUC is solved without reserves, considering only the errors in load forecasting and system contingencies. In [11], SCUC is solved incorporating load shedding for stable and contingency condition also. Binary/Real Coded Artificial

Bee Colony (BRABC) algorithm is used for solving thermal unit commitment in [12].

Renewable energy sources play a key role in power sector in the recent past. Solar energy has been continuously growing which is motivated by incentives and has reduced operating and capital costs. The renewable energy sources results in about 11% reduction in CO2 emissions levels of the year 2012 [13]. But, the variation in output of renewable sources with time and the complications in storing the energy limits the deployment of renewable sources to supply the entire peak and base load. The intermittent nature of solar irradiation is a challenging constraint to the power system operators since they should balance the demand and supply continuously in real time environment. The operational costs increases, because the system operators has to secure additional operating flexibility to balance the variations and uncertainties in solar power generated. Many approaches have been proposed to deal with the the stochastic and intermittent nature of renewable energy sources. In [14] solar radiation is characterized by distribution functions. The incorporation of any renewable energy source to the network increases balancing requirement and thereby associated costs [15].

1.1 Proposed work.

In SCUC , the units are committed satisfying the network, system and security constraints. The incorporatiation of solar power in SCUC problem gains attention since, solar energy is intermittent in nature. The ramp rate constraints may be violated depending on the solar energy available. The following case studies are analysed in this paper

a. SCUC incorporating solar farm for all seasons in 6 bus test system

b. SCUC incorporating solar farm for all seasons in South Indian 86 bus utility

c. SCUC incorporating solar farm for all seasons in South Indian 86 bus utility considering losses.

The four seasons considered here are summer, winter, spring and autumn.

2. Problem Formulation

The main objective of SCUC problem is to minimize the generation cost by satisfying the equality and inequality constraints along with transmission, network and security constraints The objective function is given by

Minimize

$$TC = \sum_{t=1}^{T}\sum_{i=1}^{N} \left[F_i(P_{(i,t)}) * I_{(i,t)} + SU_i^t * I_{(i,t)} * (1 - I_{(i,t-1)}) + SD_i^t * (1 - I_{(i,t)}) \right] \quad (1)$$

where,

TC- Total cost , *N*- number of units, *i*-1..*N* (generators), *t*-1...*T(*hour index), $P_{(i,t)}$ -Real power output of generating unit *i* at time *t* (MW), $I_{(i,t)}$ - ON (1) and OFF (0) state of unit *i* at time *t* , SU_i^t, SD_i^t - Startup cost and shut down cost of generating unit *i* at time *t*, respectively.

$$F_i(P_{(i,t)}) = a + b * P_{(i,t)} + c * P_{(i,t)}^2 \quad (2)$$

where,

$F_i(P_{(i,t)})$ - Cost function of i^{th} unit in \$/h, a , b , c -Cost co-efficients of thermal generators.

Subject to the following constraints:

Power balance constraints

$$P_{Gi,t} - P_{Di,t} = V_{i,t}\sum_{j=1}^{N} V_{j,t}(G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}) \quad i \in N_{B-1} \quad (3)$$

$$Q_{Gi,t} - Q_{Di,t} = V_{i,t}\sum_{j=1}^{N} V_{j,t}(G_{ij}\sin\theta_{ij} - B_{ij}\cos\theta_{ij}) \quad i \in N_{PQ} \quad (4)$$

where,

$P_{Gi,t}, Q_{Gi,t}$ - The real and reactive power generation at bus *i* at time *t, r*espectively, $P_{Di,t}, Q_{Di,t}$ - The real and reactive power demand in bus *i* at time *t*, respectively, G_{ij}, B_{ij} - Conductance and susceptance between bus *i* and bus *j*, respectively, $V_{i,t}$ -Voltage magnitude of bus *i* at time *t* (pu), N_B -Number of busses, N_{B-1} - Number of busses excluding slack bus. N_{PQ} - Number of *PQ* buses

Spinning reserve constraints

$$\sum_{i=1}^{N}(P_{i,\max} * I_{(i,t)}) \geq Load_t,\ k \in [1,T] \quad (5)$$

where,

t - Time index ,*T* - the total number of hour.

Unit constraints

Minimum Up and Down time constraints

A unit must be either in on or off condition for a minimum period before it can be shut down or brought online respectively.

$$[X^{on}(i,t-1) - T^{on}(i)]*[I_{(i,t-1)} - I_{(i,t)}] \geq 0 \quad (6)$$

$$[X^{off}(i,t-1) - T^{off}(i)]*[I_{(i,t)} - I_{(i,t-1)}] \geq 0 \quad (7)$$

where,

$X^{on}(i,t), X^{off}(i,t)$ - ON and OFF duration of unit *i* at time *t*, respectively, $T^{on}(i), T^{off}(i)$ - Minimum up (MUT) and down (MDT) time of unit *i*, respectively.

Unit ramp constraints

Ramp rate limits provides the minimum time taken by the generator to turn on/off. The uptime and downtime ensures the time for which the generator stays either in on or off condition.

$$P_{(i,t)} - P_{(i,t-1)} \leq UR(i) \quad (8)$$

$$P_{(i,t-1)} - P_{(i,t)} \leq DR(i) \quad (9)$$

where,

$UR(i)$, $DR(i)$- Ramp-up and ramp down rate limit of i^{th} generator unit

Security constraints

$$V_i^{\min} \le V_{i,t} \le V_i^{\max} \qquad i \in N_{B-1} \tag{10}$$

$$\left|BF_{i,t}\right| \le BF_i^{\max} \qquad i \in N_B \tag{11}$$

where,

$V_i^{\min}, V_i^{\max}$ - Minimum and maximum limits of voltages in bus i (pu), respectively. $BF_{i,t}$ -Power flowing through branch i at a specified time t (MVA) , $BF_i^{\max}$- Maximum power flow for branch i (MVA).

Reactive power generation limits

$$Q_{Gi}^{\min} \le Q_{Gi,t} \le Q_{Gi}^{\max} \tag{12}$$

where,

$Q_{Gi}^{\min}$, $Q_{Gi}^{\max}$-Minimum and maximum limits for reactive power generation for unit i, respectively.

3. ABC Algorithm

The ABC algorithm introduced by Karaboga [16,17] inspires the intelligent behavior of the honey bees for the search of nectar sources surrounding their hives. The total number of bees in the colony is divided into employed, onlookers (unemployed) and scout bees. The colony is separated into equal number of employed bees and onlooker bees. Every solution consists of a set of optimization parameters that represents the position of a food source. Here, the number of food sources is same as that of the total number of employed bees. The quality of food source and its position determines the fitness value. The process of searching the good food source is applied for finding the optimal solution. The employed bees have the responsibility to find the food sources which shares the information to the onlooker bees by performing waggle dance. The onlooker bees have the role of selecting the best food source with higher quality based on the information. So the food source chosen by the employed bees can be either selected or rejected by the onlooker bees. The employed bee corresponding to an abandoned food source is converted into a scout bee and it becomes and employed bee again by finding a new food source. If the food source is rejected because of low quality, then the employed bees are converted into scout bee again and it will search for new food sources randomly. There are three steps in each search cycle of the ABC algorithm. Initially, the employed bees are sent to the food sources and the nectar amount in each food source is evaluated. The information regarding the nectar is shared; bye evaluating the amount of nectar available in each food source the onlooker bees select the food source regions. The scout bees are chosen next and directed out to find the new food sources.

The various steps for the proposed method is given below:

Step 1:

Specify the line and bus datas, generator cost coefficients, and the generation limits for the given test system. Initialize the parameters for ABC algorithm

Step:2

Create initial random population $M = [\, X_1, X_2, X_3, \ldots. X_m \,]^T$ of m solutions (food positions) , where m represents the total size of the population. Each solution is given by $X_i = [\, P_{i1}\ P_{i2} \ldots\ldots P_{ij.} \ldots. P_{iD} \,]$, i= 1,2,3,….m and j= 1,2.3…D, where D is the total number of parameters to be optimized.. The real power generations are uniformly distributed between their minimum and maximum values, denoted by

$$P_{ij} = P_{j\,min} + rand(0,1) * \left(P_{j\,max} - P_{j\,min}\right) \tag{13}$$

Step:3

Here , using (1) the fitness value of each food source is evaluated for all the employed bees in the colony. Select the best fitness value among the inviduals and the corresponding minimum cost. The parameters that are responsible for the above the minimum cost is also selected. Repeat the following with setting a cycle count of one for each until the count reaches the the maximum cycle number (MCN) , which is also the termination criteria.

Step 4

Here the employed bee modifies the position to find a new food source. The new food position is given by

$$x_{ij} = x_j^{min} + rand(0,1) * \left(x_j^{max} - x_j^{min}\right) \tag{14}$$

Where x_j^{min} and x_j^{maxn} are the lower upper and bounds of the food source position with dimension j. The new position of the food source is checked for all the constraints given in section 3. If any of the constraint is violated, then they are set to the maximum limits. Now the fitness function for the new food position is calculated, and compared with the previous fitness value (step.3). If the fitness value of the new food position is better than previous one, then the old position is replaced with the new one. If the fitness value of the new position is worst than the previous one, then the old position is retained.

Step:5

After completing the search process, the employed bees share the information regarding the food sources and positions to the onlooker bee. The onlooker bee select a food position which is based on the probability given by

$$P_i = \frac{fit_i}{\sum_{n=1}^{D} fit_n} \tag{15}$$

Where fit_i denotes the fitness value of the food source “i” , , i = 1,2,3…D. Roulette wheel selection is employed to place the onlookers onto the food source sites.

Step 6:

The onlookers produces a modification on their position in its memory . The nector amount of the candidate source is checked. If the nector available in the new food is equal or better than the old source, then the old one is replaced by the new food position. Else, the old food position is retained in the memory. The is carried out using greedy selection mechanism.

Step:7

If the solution for a particular food source is not improving after a number of trials, the corresponding food source is abandoned. The scout bee finds a new food source. The best solution achieved so far is memorized and the cycle count is incemented.

Step:8

The process is stopped when the termination criteria is satisfied (MCN). The best fitness value and its corresponding food position is memorized at the end of the termination criteria.

4. Parameter Selection

For any optimization technique, selection of parameters plays an important role. In ABC algorithm, parameters such as the size of the colony, the total number of employed bees (ne) and unemployed bees (No) and the limit value (LM) should be selected before implementing the algorithm. . This wlll result in better convergence. As per Karaboga's and Basturk's ABC algorithm ,the number of employed bees and onlooker bees are taken as 50% each of the colony size. The colony size and limit values are selected from test cases by varying the control parameters while keeping the other constant. The parameters are selected after performing a trail run for 30 times.

4.1 Setting of colony size for optimal location

In ABC algorithm, selection of colony size is an important task. The limit value is set to 0.1neD to analyze the effect of colony size towards the fitness value. The size of the colony is then varied between 50 and 800 and the performance is studied. Fig 1 shows the difference of mean cost in economic dispatch for various values of colony size. It is observed from Fig. 1 that a lower fitness value is obtained when colony size is 300. The mean cost is high of the colony size is less than 300 and there is no substantial change in the value of mean cost if the colony size is more than 300; the computational time is increased in this case. Therefore, a better efficiency can be obtained if the colony size is in between 200-300. So the colony size is taken as 300.

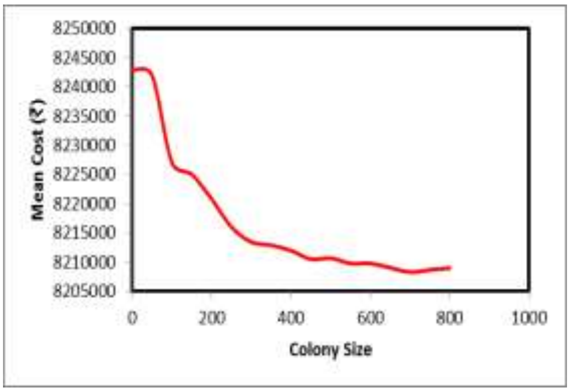

Fig. 1 Effect of colony size on mean cost

4.2 Setting of limit value

To realize the influence of limit value on the mean cost, the colony size is fixed as 300. Fig 5 shows the cost variation for different ''limit'' values from 0.001neD to 0.5neD, where ne denotes the number of employed bees and D is the number of parameters to be optimized. The mean cost obtained at lower magnitude of limit values (0.001neD and 0.005neD) is worse compared to the results obtained with the moderate values for limit values (0.01neD to 0.5neD). Convergence characteristics of the mean cost for different limit values are shown in Fig 2. It is observed from Fig. 2 that, when the limit value is very low, the learning rate of ABC is faster in the earlier stage, but settles down to a lower fitness value. Hence a moderate value for limit count (0.3neD) is considered.

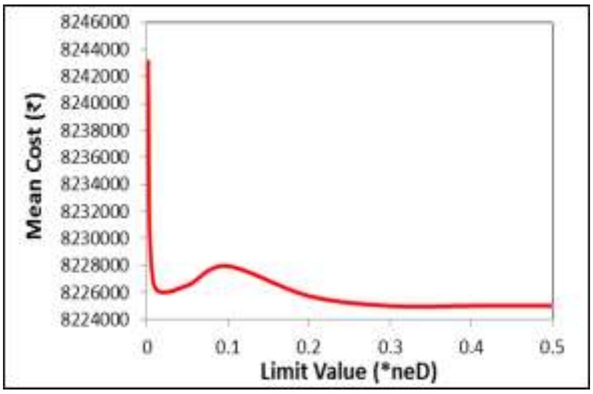

Fig. 2 Effect of limit value on mean cost

5. Modelling of Solar Farm

Beta distribution function is employed to model Solar farm [18]. Beta distribution model is considered as one of the suitable model for mathematical representation of probability density function (PDF). The variation in irradiance of solar panel is given by

$$f_b(s) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} s^{(\alpha-1)} (1-s)^{(\beta-1)}; 0 \le s \le 1; \alpha, \beta \ge 0 \tag{16}$$

where $\beta = (1-\mu)\left(\frac{\mu(1+\mu)}{\sigma^2} - 1\right)$, $\alpha = \frac{\mu\beta}{1-\mu}$,

$f_b(s)$ is Beta distribution function with α and β as parameters , $\Gamma(°)$ denotes the gamma function , s is the variable which indicate the randomness of solar irradiance (kw/m^2). μ is the mean and σ is the standard deviation of s for the specific time duration.

The output power of a solar array is

$$P(s) = P_o(s) * f_b(s) \tag{17}$$

The total output power of the solar array for a specific time is

$$TP = \int_0^1 P_o(s) * f_b(s) ds \tag{18}$$

Power output of any panel at an irradiance s is

$$P_o(s) = N * FF * \mathrm{V}_y * I_y \tag{19}$$

where N denotes the total number of solar arrays.
The technical specifications of a 220 W solar panel considered for the analysis are given in Table 1. The study period for the case study is divided into 4 seasons namely summer, winter, autumn and spring. The mean and standard deviations for these 4 seasons are furnished in Table 2. This is calculated from the solar data forecasted.

Table 1: Technical Specifications of 220W PV panel[19]

S.No	Parameter	Value
1.	Maximum Power (P_{MAX})	220W
2.	Maximum Voltage(V_{MAX})	30.29V
3.	Maximum Current (I_{MAX})	7.23A
4.	Open circuit voltage (V_{OC})	36.42V
5.	Short circuit Current (I_{SC})	7.77A
6.	Efficiency	13.4%
7.	Operating Temperature	43^{O}C

Table 2: Mean and Standard deviation for Irradiation levels

Time (Hour)	Mean	Standard Deviation	Time (Hour)	Mean	Standard Deviation
1	0	0	12	0.7663	0.163109
2	0	0	14	0.632141	0.153182
3	0	0	15	0.472228	0.133641
4	0	0	16	0.296098	0.081885
5	0	0	17	0.111815	0.047759
6	0	0	18	0.002793	0.001947
7	0.222196	0.056958	19	0	0
8	0.42612	0.094075	20	0	0
9	0.613065	0.125786	21	0	0
10	0.763489	0.130652	22	0	0
11	0.844174	0.14108	23	0	0
12	0.853043	0.146666	24	0	0

6. Results and Discussions

The proposed methodology is executed in a processor with the specifications of 2.30 GHz, Windows 8.1 with 8 GB of RAM. The shutdown cost of units is not considered and it is assumed as zero. The line and generation data for 6 bus system is obtained from [20, Appendix A and B]. The South Indian 86 bus utility consists of 86 buses with 131 transmission lines and 17 generators. The network data for the South Indian 86 bus utility is available in [12,21]. The colony size is considered as 300 and the MCN is taken as 200 for both the test systems.

Case 1: 6 bus test system

Here, Security Constrained Unit Commitment is carried out in a 6 bus system applying ABC algorithm. Here the solar energy is considered as negative demand and included in the 24 hour load profile. The 24 hours load demand is taken as constant for all seasons. The solar power is forecasted for each hour depending on the irradiation (4 seasons) and the data are furnished in Table 3. This is carried out for a time period of 24 hours.

Table 3: Solar power generation in 24 hours for 4 seasons

Hour\ Season	Spring	Summer	Autumn	Winter	Hour\ Season	Spring	Summer	Autumn	Winter
1	0	0	0	0	13	50.4	49.08	46.8	41.7
2	0	0	0	0	14	49.2	41.03	37.6	35.4
3	0	0	0	0	15	49.2	31.124	26.8	25.8
4	0	0	0	0	16	38.1	29.86	15.2	14.09
5	0	0	0	0	17	24.09	27.56	11	5.26
6	0	0	0	0	18	9.2	1.38	0	0
7	13.6	15.00	13.7	10.48	19	0	0	0	0
8	28.6	28.23	26.22	22.71	20	0	0	0	0
9	42.9	39.89	37.9	34.67	21	0	0	0	0
10	42.34	48.91	45.2	42.34	22	0	0	0	0
11	44.6	53.68	50	45.77	23	0	0	0	0
12	47.5	54.21	50	44.87	24	0	0	0	0

In this case, 700000 solar panels each rated for 220W are considered. From Table 3. it is clear that the power generated varies significantly with respect to time. The commitment schedule for the three generators in summer season is given in Table 4. The units are committed in such a way that the load demand is met with minimal cost while satisfying the system, network and security constraints. In this case, the cheap unit G1 is committed for the entire 24 hour horizon (4 seasons) and the costly units G2 and G3 are committed only for specific hours so that the operating cost is minimized.

The network and security constraints are checked for any violation, and are found to be within their limits. The generation dispatch without incorporating solar farm is given in Table 5, the total generation cost is 84263.60 $. The generation cost for all 4 seasons with solar farm is given in Table 6. The generation dispatch for 24 hours with solar farm and the corresponding generation cost is furnished in Table 7. Here the installation cost of solar energy is not considered. The cheapest unit among the three responds to the variations of solar power generation. It is observed that the probability of maximum solar power generation leads this unit to reduce its active power output to a lower value. As the solar power is varying with time, the thermal power generation also varies, which should satisfy the ramp constraint of the generators. Here, all the parameters are within limits. Since, the constant load is assumed for all seasons, the variation in solar power influences the generation cost significantly. The solar power output in summer season is comparatively high so that the generation cost is reduced.

Table 4 Commitment schedule for 6 bus system incorporating solar power

Hours	G_1	G_2	G_3	Hours	G_1	G_2	G_3
1	1	1	0	13	1	1	1
2	1	0	0	14	1	1	1
3	1	0	0	15	1	1	1
4	1	0	0	16	1	1	1
5	1	0	0	17	1	1	1
6	1	0	0	18	1	1	1
7	1	0	0	19	1	1	1
8	1	0	0	20	1	1	1
9	1	1	0	21	1	1	1
10	1	1	1	22	1	1	1
11	1	1	1	23	1	1	1
12	1	1	1	24	1	1	1

Table 5 Generation dispatch without solar farm in 6 bus system

Hour	G1 (MW)	G2 (MW)	G3 (MW)	Hours	G1 (MW)	G2 (MW)	G3 (MW)
1	169.38	10	0	13	220.00	10.50	17.58
2	169.09	0	0	14	219.33	10.00	20
3	162.44	0	0	15	219.10	15.52	20.00
4	158.21	0	0	16	219.90	32.00	20.00
5	158.74	0	0	17	219.38	51.40	20.00
6	164.22	0	0	18	219.20	13.50	20
7	177.50	0	0	19	218.28	13.53	20
8	199.00	0	0	20	212.90	10	20
9	200.54	10.00	0	21	219.59	10	13.5
10	204.44	10.00	10.00	22	211.74	10	10.89
11	213.88	10.44	10.00	23	198.93	0	0
12	219.20	10.00	18.88	24	191.58	0	0

Table 6 Generation cost for all seasons in 6 bus system

S.No	Season	Generation cost ($)
1	Without Solar	84263.60
2	Spring	72959.74
3	Summer	72232.07
4	Autumn	73045.86
5	Winter	74042.78

Table 7 Generation dispatch with solar farm in 6 bus system

Hour	G1 (MW)	G2 (MW)	G3 (MW)	Hours	G1 (MW)	G2 (MW)	G3 (MW)
1	169.38	10	0	13	182.86	8.72	14.61
2	169.09	0	0	14	188.32	8.57	17.06
3	162.44	0	0	15	197.27	14.03	17.96
4	158.21	0	0	16	208.50	30.33	18.95
5	158.74	0	0	17	215.67	50.56	19.63
6	164.22	0	0	18	219.20	13.50	20
7	167.03	0	0	19	218.28	13.53	20
8	176.27	0	0	20	212.90	10	20
9	167.37	8.34	0	21	219.59	10	13.5
10	165.71	8.10	8.10	22	211.74	10	10.89
11	171.76	8.39	8.03	23	198.93	0	0
12	178.40	8.13	15.30	24	191.58	0	0

Case 2: 86 bus South Indian utility

Here, the SCUC is carrier out in a South Indian 86 bus utility incorporating solar farm. The solar output is considered as negative demand in a 24 hour load profile. Here 2727272 numbers of solar panels, each rated for 220W is considered. The power generated for all four seasons is forecasted using Beta distribution function. The power generated for a 24 hour time span for all 4 seasons is shown in Fig 3.

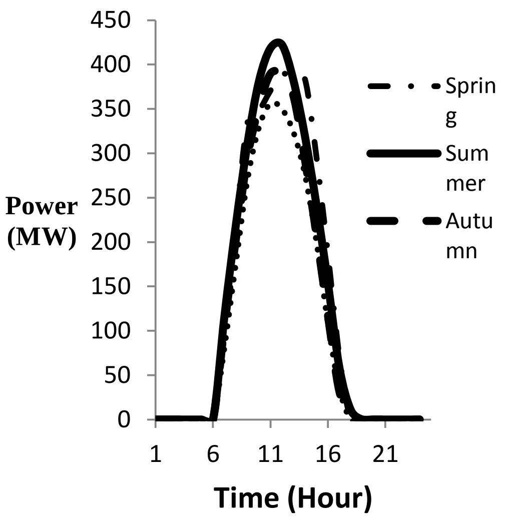

Fig 3 Solar Power generation in all seasons for 86 bus system

Initially the commitment status for the generators are obtained and economic dispatch considering the security constraints is carried out next with the generators that are committed for the specified load demand. The commitment status for is furnished in Table 8. It is observed that the connected load for South Indian system which is considered in this case is high, and transmission line parameters have resulted in considerable line losses, all the 17 generators are committed for the entire time horizon of 24 hours. The generation cost and dispatch in the case is furnished in Table 9. The total generation cost is ` 8241567.737

In the case discussed above, the solar power generated is considered as lossless. Since, the solar farm is not feeding the local load; the power should be transmitted through the existing transmission lines. This power flow is carried out in such a way that the objective function is minimised satisfying the constraints. As, the transmission lines is having specific power loss, the entire solar power generated cannot be utilized by the load. In this case, a specific percentage of transmission loss is considered for solar power also. This loss is calculated in proportion to the percentage of loss incurred for a specific load before incorporating solar farm. SCUC is carried out and the dispatch obtained is furnished (Summer season) in Table 10. It can be noted that the output of thermal generators are increased since it has to account for the losses also. This has increased the generation cost also since the solar power generated is constant for a time horizon of one hour. This variation in power generation will be restricted by the ramp limit of generator. In this case also, all constraints are satisfied. The generation cost for all 4 seasons with solar farm is furnished in Table 11. It is inferred that, the generation cost is varying depending on variation in solar power in various seasons.

Table 8 Commitment status of South Indian 86 bus system

Time (h)	Commitment Status of units (ON/OFF)
1	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
3	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
4	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
5	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
6	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
7	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
8	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
9	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
10	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
11	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
12	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
13	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
14	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
15	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
16	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
17	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
18	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
19	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
20	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
21	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
22	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
23	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
24	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

Table 9 : Generation Dispatch in MW and cost in ` for Case:2 without loss

Hour	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17
	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)
1	106.62	106.62	106.62	106.62	106.62	116.6	116.54	116.57	116.57	102.56	102.56	102.56	121.98	121.98	121.98	121.98	121.98
2	117.17	117.17	117.17	117.17	117.17	109.8	109.84	109.84	109.84	103.85	103.85	103.85	98.1	98.1	98.1	98.101	98.1
3	146.57	146.57	146.57	146.57	146.57	83.17	83.17	83.17	83.17	146.78	146.78	146.78	146.61	46.61	146.61	146.61	146.61
4	167.54	167.54	167.54	167.54	167.54	56.34	56.34	56.34	56.344	38.54	38.54	38.54	109.44	109.44	109.44	109.44	109.44
5	125.68	125.68	125.68	125.68	125.68	59.55	59.55	59.55	59.559	69.24	69.24	69.24	98.98	98.98	98.98	98.98	98.98
6	145.3	145.3	145.3	145.3	145.3	130.8	130.8	130.82	130.82	64.17	64.17	64.17	42.87	42.87	42.87	42.87	42.87
7	147.74	158.58	147.74	147.74	147.74	72.9	72.9033	72.90	72.903	68.44	68.44	68.44	80.89	80.89	80.88	80.89	80.89
8	100.12	114.41	100.12	100.17	100.12	98.32	98.32	98.32	98.324	76.36	76.36	76.36	92.52	92.52	92.52	92.52	92.52
9	74.063	90.2	74.06	74.06	74.06	88.81	88.81	88.81	88.816	84.58	84.58	84.58	97.36	97.36	97.36	97.36	97.36
10	76.078	97.87	76.078	76.07	76.07	83.18	83.18	83.18	83.181	73.182	73.18	73.18	87.04	87.04	87.04	87.04	87.04
11	70.28	97.86	70.28	70.28	70.28	65.89	65.89	65.89	65.89	62.29	62.29	62.29	58.84	58.84	58.84	58.84	58.84
12	80.5	109.71	80.5	80.5	80.5	84.59	84.59	84.59	84.593	47.11	47.11	47.11	62.98	62.98	62.98	62.98	62.98
13	127.22	161.64	127.22	127.22	127.22	85.61	85.60	85.60	85.605	65.26	65.26	65.26	55.89	55.891	55.89	55.89	55.89
14	91.76	109.13	91.76	91.76	91.76	114.7	114.69	114.69	114.69	114.84	114.84	114.84	94.89	94.89	94.89	94.89	94.89
15	108.21	122.95	108.23	108.21	108.21	135.3	135.31	135.31	135.31	143.87	143.87	143.87	63.47	63.47	63.47	63.47	63.47
16	77.96	84.56	77.96	77.96	77.961	97.69	97.68	97.69	97.69	156.44	156.44	156.44	126.34	126.34	126.34	126.3	126.3
17	133.97	139.47	133.97	133.97	133.98	13.03	13.03	13.03	13.034	87.20	87.20	87.20	98.70	98.70	98.70	98.70	98.70
18	149.65	150.63	149.65	149.65	149.66	100.7	100.69	100.7	100.7	76.77	76.77	76.77	65.74	65.74	65.74	65.74	65.745
19	205.45	205.45	205.45	205.45	205.46	54.7	54.70	54.70	54.705	145.22	145.22	145.22	77.30	77.30	77.30	77.30	77.30
20	155.69	155.69	155.69	155.69	155.69	15.15	15.14	15.14	15.146	101.35	101.35	101.35	114.7	114.7	114.7	114.7	114.7
21	151.07	151.07	151.07	151.07	151.07	85.25	85.24	85.24	85.249	148.84	148.84	148.84	58.56	58.56	58.560	58.56	58.56
22	100.27	100.27	100.27	100.27	100.27	83.7	83.69	83.69	83.696	159.6	159.6	159.6	109.4	109.4	109.40	109.4	109.4
23	132.22	132.22	132.22	132.22	132.22	131.3	131.38	131.35	131.35	125.09	125.09	125.09	124.63	124.63	124.63	124.63	124.63
24	163.05	163.05	163.05	163.05	163.05	150.7	150.72	150.73	150.73	49.92	49.92	49.921	110.76	110.76	110.76	110.76	110.76
Total Generation cost (`)										8241567.737							

Table 10 : Generation Dispatch in MW and cost in ` for Case : 2 with loss

Hour	P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	P5 (MW)	P6 (MW)	P7 (MW)	P8 (MW)	P9 (MW)	P10 (MW)	P11 (MW)	P12 (MW)	P13 (MW)	P14 (MW)	P15 (MW)	P16 (MW)	P17 (MW)
1	106.62	106.62	106.62	106.62	106.62	116.57	116.57	116.57	116.57	102.56	102.56	102.56	121.98	121.98	121.98	121.98	121.98
2	117.17	117.17	117.17	117.17	117.17	109.85	109.85	109.85	109.85	103.86	103.86	103.86	98.1	98.1	98.1	98.1	98.1
3	146.58	146.58	146.58	146.58	146.58	83.18	83.18	83.18	83.18	146.78	146.78	146.78	46.61	46.61	46.61	46.61	46.61
4	167.54	167.54	167.54	167.54	167.54	56.34	56.34	56.34	56.34	38.54	38.54	38.54	109.44	109.44	109.44	109.44	109.44
5	125.69	125.69	125.69	125.69	125.69	59.56	59.56	59.56	59.56	69.25	69.25	69.25	98.99	98.99	98.99	98.99	98.99
6	145.31	145.31	145.31	145.31	145.31	130.82	130.82	130.82	130.82	64.18	64.18	64.18	42.88	42.88	42.88	42.88	42.88
7	148.05	158.58	148.05	148.05	148.05	73.05	73.05	73.05	73.05	68.58	68.58	68.58	81.05	81.05	81.05	81.05	81.05
8	100.52	114.42	100.52	100.52	100.52	98.71	98.71	98.71	98.71	76.66	76.66	76.66	92.89	92.89	92.89	92.89	92.89
9	74.51	90.21	74.51	74.51	74.51	89.35	89.35	89.35	89.35	85.09	85.09	85.09	97.95	97.95	97.95	97.95	97.95
10	76.68	97.88	76.68	76.68	76.68	83.84	83.84	83.84	83.84	73.76	73.76	73.76	87.73	87.73	87.73	87.73	87.73
11	71.04	97.87	71.04	71.04	71.04	66.6	66.6	66.6	66.6	62.97	62.97	62.97	59.48	59.48	59.48	59.48	59.48
12	81.3	109.71	81.3	81.3	81.3	85.44	85.44	85.44	85.44	47.59	47.59	47.59	63.61	63.61	63.61	63.61	63.61
13	128.18	161.64	128.18	128.18	128.18	86.24	86.24	86.24	86.24	65.75	65.75	65.75	56.31	56.31	56.31	56.31	56.31
14	92.24	109.14	92.24	92.24	92.24	115.29	115.29	115.29	115.29	115.44	115.44	115.44	95.39	95.39	95.39	95.39	95.39
15	108.62	122.95	108.62	108.62	108.62	135.82	135.82	135.82	135.82	144.41	144.41	144.41	63.71	63.71	63.71	63.71	63.71
16	78.15	84.56	78.15	78.15	78.15	97.92	97.92	97.92	97.92	156.81	156.81	156.81	126.64	126.64	126.64	126.64	126.64
17	134.13	139.48	134.13	134.13	134.13	13.05	13.05	13.05	13.05	87.31	87.31	87.31	98.81	98.81	98.81	98.81	98.81
18	149.69	150.63	149.69	149.69	149.69	100.72	100.72	100.72	100.72	76.79	76.79	76.79	65.76	65.76	65.76	65.76	65.76
19	205.46	205.46	205.46	205.46	205.46	54.7	54.7	54.7	54.7	145.22	145.22	145.22	77.3	77.3	77.3	77.3	77.3
20	155.69	155.69	155.69	155.69	155.69	15.15	15.15	15.15	15.15	101.35	101.35	101.35	114.7	114.7	114.7	114.7	114.7
21	151.07	151.07	151.07	151.07	151.07	85.25	85.25	85.25	85.25	148.84	148.84	148.84	58.56	58.56	58.56	58.56	58.56
22	100.27	100.27	100.27	100.27	100.27	83.7	83.7	83.7	83.7	159.6	159.6	159.6	109.4	109.4	109.4	109.4	109.4
23	132.22	132.22	132.22	132.22	132.22	131.35	131.35	131.35	131.35	125.09	125.09	125.09	124.63	124.63	124.63	124.63	124.63
24	163.05	163.05	163.05	163.05	163.05	150.73	150.73	150.73	150.73	49.92	49.92	49.92	110.76	110.76	110.76	110.76	110.76
Total Generation cost (`)									8236021.70								

Table 11 Generation cost for all seasons in 86 bus system

S.No	Season	Generation cost without loss (`)	Generation cost with loss (`)
1	Summer	8212432.00	8236021.70
2	Spring	8264398.07	8264398.07
3	Autumn	8323354.14	8344246.54
4	Winter	8392204.81	8411504.68

7 Conclusion

Security Constrained Unit Commitment (SCUC) on combined solar thermal generating systems with ABC algorithm is discussed in this paper. The solar power for all 4 seasons is forecasted using Beta distribution function and incorporated into SCUC. Case studies without and with the incorporation of transmission line losses are carried out. The influence uncertainty nature in solar power in thermal power generation and generation cost is also analysed. It is inferred that, for a fixed demand, the thermal generation varies with seasons since the probability of generating solar power depends on the irradiation. Incorporation of solar energy is not having any impact on commitment status of generators, since the entire generation of a thermal plant is not replaced by solar power. Placing the solar power generation near the load centre and supplying the local load may reduce transmission losses.

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Appendix A
Generaton data of 6 bus system

Generators		G_1	G_2	G_3
Parameters				
Bus No		1	2	6
Cost coefficients	a	176.9	129.9	137.4
	b	13.5	32.6	32.6
	c	0.0004	0.001	0.001
active power maximum, MW		200	100	20
active power minimum, MW		100	10	10
reactive power maximum,MVAR		200	70	50
reactive power minimum, MVAR		-80	-40	-40
initial status of unit, h		4	2	2
min down of unit, h		4	2	2
min up of unit, h		4	2	2
ramp, MW/h		55	50	20
startup, MBtu		100	200	0
fuel price, $/MBtu		1	1	1

Appendix B
Hourly load data of 6 bus system

Hour	Pd(MW)	Hour	Pd(MW)
1.	178.69	13.	247.03
2.	168.45	14.	248.47
3.	161.84	15.	253.83
4.	157.83	16.	270.9
5.	158.16	17.	290.12
6.	163.69	18.	251.68
7.	176.86	19.	250.89
8.	198.21	20.	242.1
9.	209.67	21.	242.05
10.	223.54	22.	231.68
11.	233.18	23.	198.07
12.	240.8	24.	190.67