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Optimal Placement Of Energy Storage Units Using Particle Swarm Optimization With In A Deregulated Power System

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Abstract
This paper investigates about the best placement of energy systems in a deregulated power system. Due to unpredictability nature of renewable generation like wind, transmission congestion is happening. We are placing distributed energy storage systems as a key to properly make use of transmission capacity, reduction in cost due to transmission upgrading and maximizing wind utilization during high wind penetration levels. After placing energy storage system we automatically minimize hourly social cost by utilizing the wind generation. Wind and load are analytically designed by curve fitting approach. To maximize the social welfare of the system as well as for optimal placement we are using particle swarm optimization (PSO) enhanced market based probabilistic optimal power flow (POPF). An analytical simulation has been developed to evaluate the economics of the storage system based on the energy from wind generation. The best placement of distributed energy storage units is evaluated by particle swarm optimization with less convergence time which improves system performance without exceeding thermal limits of transmission lines. The MATLAB programming is used to carry out the proposed Particle swarm optimization (PSO) for the IEEE 24-bus system. The prospective impact of distributed storage on wind utilization is additionally evaluated through several case studies.

Keywords: Particle Swarm Optimization (PSO), Wind penetration level, Compressed air energy storage system, Locational Marginal Price.

1 .INTRODUTION

With huge increase in electrical energy demand in present situations the system operators is employing usage of renewable generation. From the last few decades, development in deregulated structure power market there is a rapid increase in the event of utilizing wind generation. Due to unpredictability of wind nature, operation of grid faces several challenges. Considering these challenges system operators in the power market enabling different technologies to obtain the efficient energy and increase in social welfare. Energy storage is one of the best technologies which can enlarge grid performance which is integrated by renewable energy sources primarily wind energy [2]. These energy sources additionally help in handling peak load requirement and eliminating transmission as well as distribution system upgrading by efficiently utilizing present capacities of transmission system.

According to renewable portfolio standards (RPS), usage of renewable generation with unpredictability nature needs convenient design for maximising the service of energy storage system. During this process a question raised about optimal placement of this service. Optimal placement of storage unit with high penetration in renewable generation defines several benefits. Plays major role in peak-shaving, reduction of cost regarding to T&D enhancing, maintains transmission thermal limits and storage based social benefits. Depending upon the load and wind generation output storage gets charged and discharged according to contract basis between the wind generators or to the grid operators. Storage units are implemented to prevent penalties correlated with producing inadequate energy than the cleared schedule. Several investigations are pointed out the optimal placement of storage systems with use of renewable generation but none of these considered the intermittency nature of renewable generation [7]-[8]. In previous studies, they employed several optimising techniques converging to local minimum which increases the social cost of system in market and less utilization of wind power. In existing studies, GA-optimization is employed for obtaining the best value of objective function [1]. In this existing method, large number of parameters such as crossover, mutation and reproduction are involved which increases the convergence time for the optimizing the objective function. Due to parameter evolution complexity raises in designing the program. In addition to above problems, it doesn't have additional memory to store the previous finest values for each and every particle.

This paper proposes a Particle Swarm Optimization (PSO) enhanced market based probabilistic optimal power flow with energy storage integration with high wind penetration levels. The proposed algorithm optimally places and line-up the storage units with high convergence rate to improve social-welfare and maximizing wind utilization. The proposed two point estimation and PSO optimization can be examined under IEEE-24bus system. Remaining study of this paper obtained as follows. In area 2, overview of designing wind generation, load patterns, economics of storage system and market based POPF for cost-benefit investigation. In area3, a study of PSO is described for maximizing objective function. In section 4, simulation outcomes are displayed and discussed. The conclusion is made in section 5.

2. DESIGNING

I.DESINGING OF WIND AND LOAD PATTERNS

The unpredictability of wind generation and load is examined by using probability density functions. The analytical designing of wind speed is attained by adopting Weibull distribution whose probability density function (pdfs) given as below

$$f_v(v) = \left(\frac{k}{\lambda}\right)\left(\frac{v}{\lambda}\right)^{k-1} e^{-(\frac{v}{\lambda})^k}, o \le v \le \infty \quad (1)$$

By employing curve fitting approach and Weibull distribution parameters output of the wind power of a wind generator is achieved as below

$$G_W = \begin{Bmatrix} 0, v \le v_i, v \ge v_0 \\ \frac{v-v_i}{v_r-v_i} G_{W_r}, v_i \le v \le v_r \\ G_{W_r}, v_r \le v \le v_0 \end{Bmatrix} \quad (2)$$

For analytical modelling of load changing, Gaussian distribution and curve fitting is employed. The pdf for load variation is

$$f_L(L) = \frac{1}{\sqrt{2\pi\sigma^2 L}} exp\left[-\frac{(L-\mu_L)^2}{2\sigma_L^2}\right] \quad (3)$$

II. DESIGNING OF STORAGE SYSTEM

In this storage system employs change over time electric energy against renewable generation. The energy storehouse unit is charged by wind power when output of wind generator exceeds the load requirement. It occurs when $G_{w_t} - L_t > 0$(off-peak hours) to handle the transmission capacity. The stored energy is released at the time of the peak load hours of the day when $G_{w_t} - L_t < 0$(peak hours). Huge size and economics of the storehouse unit concern for change over time energy from wind generation in transmission side made the compressed air energy storage (CAES) and pumped hydro energy storage system(PHES) is more predominant when compared to several energy storage units. Depending upon favourable geological constraints CAES is feasible machinery for storage purpose.

1 .For charging:

$$S_t = (1 - d_s)s_{t-1} + n_s\left(G_{W_t} - L_t\right) \forall t \in T \quad (4)$$

2 .For releasing:

$$S_t = (1 - d_s)s_{t-1} + \left(G_{W_t} - L_t\right) \forall t \in T \quad (5)$$

A reservoir must indulge the condition for minimum storage S_{min} and maximum storage capacity S_{max} at time't'

$$S_{min} \le S_t \le S_{max} \forall t \in T \quad (6)$$

Assuming the equal maximum charging and discharging rate(P_{max}), the power of the storage system should satisfy the following inequality for individual hours:

$$|P_t| \le P_{max} \forall t \in T \quad (7)$$

Identical to any generator, turbine has its own ramp-up and ramp-down constraints shown as

$$G_{S_t} - G_{S_{t-1}} \le RU_S \forall t \in T \quad (8)$$

$$G_{S_{t-1}} - G_{S_t} \le RD_S \forall t \in T \quad (9)$$

III.ECONOMIC ASPECTS OF CAES

The total cost for CAES is sum of the cost of turbine, reservoir and compressor. The operational cost of CAES involves fuel cost and fixed operation and maintenance cost

$$C_{Inv} = C_S.S_{max} + C_P.P_{max} + C_C.P_{max}^C \quad (10)$$

$$C_{OP_t} = HR.G_{S_t}.C_{NG_t} + C_{OM}.P_{max} \forall t \in T \quad (11)$$

All these primary investment expenses are transformed to a sequence of systematic every year costs. The annual proportional charge is

$$A = \frac{d(1+d)^N}{(1+d)^{N+1}-1} C_{Inv} \quad (12)$$

IV. MARKET- BASED PROBABLISTIC OPTIMAL POWER FLOW (POPF)

Unpredictable factors as output of wind power and fluctuating loads can be studied in power flow calculation by taking adopting POPF. To implement probabilistic analysis in POPF, several methods are recommended such as simulation, analytical and approximate approaches. Due to several advantages of approximate methods, Point Estimation (PE) is employed. Two point estimation method (2PE) a modification of PE is adapted here to design the unpredictability of wind speed and load. This method evaluates high accuracy level when examined with several methods. The input and output arbitrary variables and the analogous nonlinear function are evaluated as

X = [Wind Speed, Loads] (13)

Y = [HSC] (14)

Y= h(X) (15)

The functional association among X and h(X) is assigned to set up two estimates of Y-variants. Here unit commitment is made to regulate the power system by effectively shut down the generators which are overpriced to perform their activity and replace with less expensive generator in that place. This gives an efficient economic operation in the changeover time electric energy from wind power.

3 .PROPOSED OPTIMIZING METHOD

PARCTICLE SWARM OPTIMIZATION

In these modern days, due to the rapid enlargement in problem dimensions and huge demand for fast optimisation algorithms system operators preferring intelligent algorithms using random search rather than overall search in problem space. This method is used to find solution for several objective optimisation problems which are facing in deregulate structured power system. These approaches also called as heuristic algorithms as they vary from one solution to another by using rules obtained from human reasoning. Several examples of heuristic algorithms are tabu search (TS), Ant Colony Optimization (ACO), simulated annealing (SA), genetic algorithms (GA), particle swarm optimization (PSO). Each and every method has its own benefits which are feasible to handle suitable problems. In this paper we propose PSO algorithm which is an experimental maximization method for maximisation of wind utilization and optimal placement for energy storage system in deregulated power market. PSO was formatted by Kennedy and Eberhart in the year 1995.

After analysing GA with PSO, asset of PSO is it has no evolution operators which are to be updated and easy application to problem environment [18]. It needs only few parameters to be modified. PSO is population search based algorithm which needs initialisation of population parameters for obtaining the optimal solution in the problem space by updating generation. PSO handles group of particles which moves in the problem solution space without any restrictions about structure or type of function to be optimised. Every particle has its own velocity and location in an N-dimensional area. Each particle sustain a trace of its member in the solution space which is related with the finest solution (fitness) obtained so far by the particular particle. This finest assessment is called personal best value (p_{best}) a further assessment obtained by the optimiser searching in the overall global search space recognized as global best value (g_{best}).Each and every particle update its position by means of information gained by present positions and velocities which is varying according to time shift of the data. The updating of particle can be done by the changing of velocities and positions which is obtained from the given below equations

$$V_i^{K+1} = WV_i^K + C_1 \times rand_1 \times \left(X_{ipbest}^k - X_i^k\right) + C_2 \times rand_2 \times (X_{igbest}^k - X_i^k) \quad (16)$$

Where,
V_i = velocity of the particle 'i'
K = velocity of particle 'i' at iteration 'k'
W = inertia weighting function which varies from 0.9 to 0.4
C_1, C_2 = acceleration weight factor normally taken as 2
X_i^k = current position of particle 'i' at iteration 'k'
i_{pbest} = p_{best} position of particle 'i'
i_{gbest} =g_{best} position of particle 'i'

The following weight function can also be obtained from below equation

$$W = W_{max} - \frac{W_{max} - W_{min}}{iter_{max}} \times iter \quad (17)$$

Where,
W_{max} = initial weight
W_{min} = final weight
iter = present iteration number
$iter_{max}$= maximum iteration number

With these equations the updating of pbest and gbest are found, the positions are updated by using below equation

$$X_i^{K+1} = X_i^K + V_i^{K+1} \quad (18)$$

PSO has less convergence time and support solutions by using separate memory when compared to GA. Here the objective function or fitness value is maximizing wind utilization which in turn improves social welfare of the system by placing the storage system in best location.

Objective Function = Max{ Wind Utilization} (19)

Algorithm for Particle Swarm Optimization enhanced POPF

STEP1. Initialisation: Initially seeking vectors likewise speed are composed promptly

Step2. After performing the optimal power flow by using market based POPF over the scheduled period depending on objective intention by fixing the p_{best} for the first searching space. The finest value obtained by comparing over all p_{best} values called g_{best} .

Step3. Velocity & position updating: Making use of the particle best and overall finest values velocity updating is done by using the above equations. Depending on the updated velocity values each and every particle position is restored.

Step4.By obtaining the new objective function the current searching particles is gathered. By examining that the value of objective function is improved by the latest p_{best} than the previous particle best value then the current p_{best} is restored. Depending on the current p_{best} value g_{best} is also restored.

Step5.If stopping criteria is satisfied then the optimal setting is obtained the optimiser will terminate the program otherwise it will go to step2

Step6: Again the procedure will gets started until the criteria is satisfied

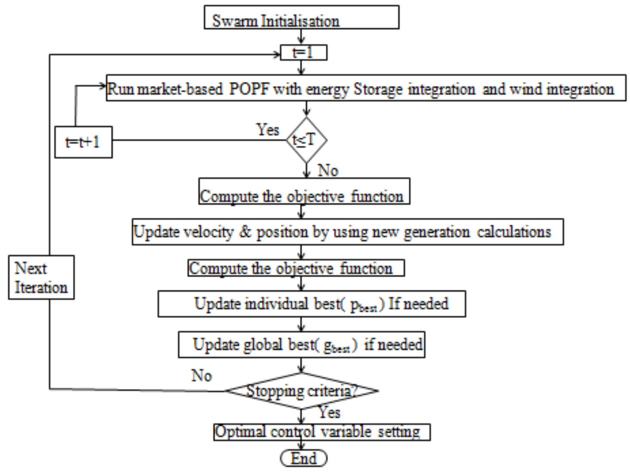

Fig.1. Flow chart for Particle Swarm Optimization (PSO)-enhanced POPF

4. CASE STUDY

This section uses the proposed method effectively for the optimal placement of the energy storage systems within the IEEE-24 bus system under two scenarios under high wind penetration level and evaluates their simulation results. Simulation results are obtained from MATLAB. The cost is evaluated by summing up the equivalent investment cost and operation cost for the 24-hour scheduling period .Wind penetration is defined as the ratio of the installed wind power capacity to the system peak load. For both the scenarios, the primary energy source is a wind farm installed at bus 14. Initially all the generating units are committed for each hour for given scheduling period. Storage systems are placed in such a way that generators having least marginal cost functions are operated over a given scheduling period which minimizes the hourly social cost of the system in turn maximising the wind utilisation.

Scenario I

This section shows the simulation results for the 45% wind penetration for the centralised storage system.

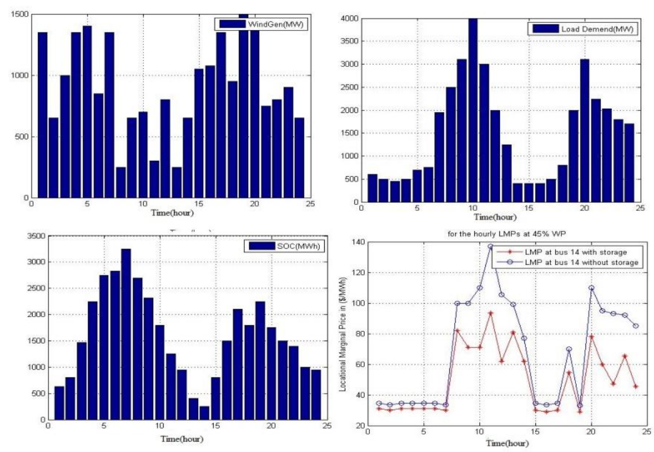

Fig.2. Simulation results for the centralised storage for 45% Wind Penetration (Scenario I)

As shown in Figure 2 energy storage system is charged during the fresh hours of the day as wind generation go beyond the system load demand or else the transmission capacity of the lines associated to wind bus. This surplus energy is gained by bilateral commitment among wind farm and storage holders. During fresh hours wind power is the fundamental source of energy to compensate load requirement as well as storage at 14 bus which is acting as a unpredictable load. In the case of peak noon time load which overtake the wind generation, the storage system acts as a generator to bid in the power pool which discharges energy by maintain the transmission line constraints. If wind generation and storage system doesn't support the system load, conventional generation is used to compensate the requirement. Again the storage is charged in between 15 and 17 period and again discharged during late hours of the day when the wind generation doesn't mitigate load requirement. The hourly Locational Marginal Prices at bus 14 along and out of storage is displayed on the above figure. Best placement of storage at the wind bus will lowers the hourly social cost during the off-peak and peak hours at which system is operating. Considering the transmission limitation capacity, expansion of transmission system is more cost effective than handling the existing transmission by adopting several storage units in the power pool. Only single storage placement cannot effectively handle this function so, multiple distributed energy storage systems is arranged as shown in the table I

TABLE I SIMULATION OUTCOME FOR OPTIMAL PLACEMENT OF ENERGY STORAGE SYSTEM (45%WP)

DISTRIBUTED STORAGE	OPTIMAL PLACEMENT (BUS)	ENERGY RATING (MWH)	POWER RATING (MW)	COST (10^3 $)	WIND UTILIZATION (%)
1-unit	14	3232.2	754.95	255.25	91.81
	14	1470.2	754.95	150.6	
2-unit	10	1762.2	498.5	164.9	97.89
	14	1470.2	754.95	150.6	
3-unit	10	1762.2	498.5	164.9	97.89
	10	0	0	0	

Table I evaluates the fact that multiple distributed storage placements can effectively handles transmission capacity and assimilation of wind power with huge penetration levels comfortably. When wind power goes beyond the load requirement the surplus energy is stored in between the two storage units which increase the wind utilization and transmission line capacity compared with centralised storage system. Cost of the CAES increases with multiple units which in turn rationalise the market revenues. Wind utilization of 91.81% with single unit is increased to 97.89% consisting of multiple units.

***Scenario* II: Distributed storage with limited capacity**
This study introduces the optimal employment of energy storage in the IEEE 24-bus system examined to geographical and physical restraints on the feasible energy and power capacities. For evaluation buses are separated into two categories of limited CAES of 1600MWh and 1400MWh for each class. Table II and figure 3 show the simulation outcome for above discussion.

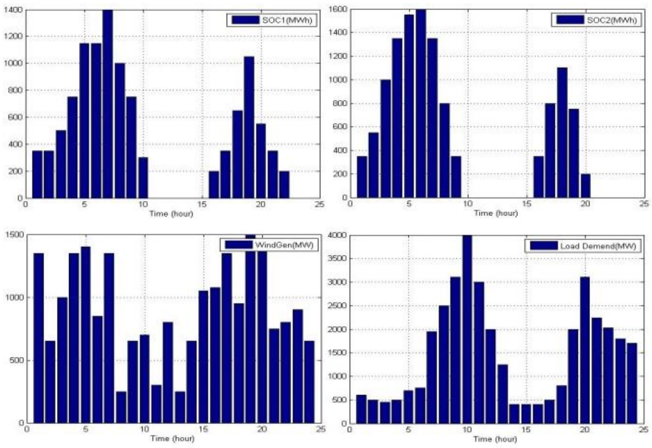

Fig.3. Simulation outcome for two –unit storage at 45%WP

TABLE II SIMULATION OUTCOME FOR OPTIMAL PLACEMENT OF DISTRIBUTED ENERGY STORAGE SYSTEM (SCENARIO II)

DISTRIBUTED STORAGE	OPTIMAL PLACEMENT (BUS)	COST (10^3 $)	WIND UTILIZATION (%)
1-unit	11	123.25	83.08
	14	126.23	
2-unit	23	123.56	94.19
	14	126.23	
3-unit	23	123.56	94.19
	11	0	

5. CONCLUSION

This paper has examined the optimal placement of energy storage unit in deregulated power system to maximise the social welfare. After analysing the wind and load data PSO-enhanced market based POPF with energy storage assimilation and wind output power maximizing wind power usage over the desired period. Economic energy model for CAES is designed. Simulation outcomes for IEEE-24bus system evaluates the benefits of allocating of wind and storage for effective integration of wind power with huge penetration levels. The best location of storage units efficiently uses the transmission capacity without violating thermal limits of the system. This reduces the cost which was used to re-establish transmission network.

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