Multi-objective optimal power dispatch of power system incorporating wind power

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ABSTRACT

Due to the uncertainty of wind flow, accurate modeling of wind energy conversion system (WECS) based power generation system and its integration with conventional fossil fuel based generation and grid becomes an imperative issue. In this context, this work attempts to model the combined operation of wind-thermal generation system in optimal power dispatch framework so that not only the cost of power generation will be minimized but also it attempts to do so while keeping the system operating voltage secure and stable. In this context, hybrid algorithm (HA) and artificial bee colony algorithm (ABCA) have been used to optimize the suitably formulated objective. The result demonstrates the superiority of HA over ABCA in obtaining the optimal solution for the proposed system.

Index Terms—Optimal scheduling; Hybrid algorithm; Voltage security

I INTRODUCTION

The uncertainty of the WECS output introduces colossal difficulties in the scheduling of the conventional generation units which may lead to vulnerable system operation. The problem of the variability of wind power has been addressed by authors in [1]. Modeling of cost components corresponding to the wind power during under and over predictions in wind integrated system are presented in [2, 3, 4]. In recent past the optimal power flow (OPF) problems have been unraveled by several of conventional and intelligent technique based algorithms [2-11]. In all these works attention is focused on solving the OPF problem of thermal generation systems and minimization of system operational cost and other operational issues. But in this proposed work, wind integrated thermal generation system is taken as the system under consideration. The OPF solution of conventional power generation system using differential evolution (DE) algorithm is analyzed in [5]. Solution of optimal power flow problem with non-smooth and non-convex generator fuel cost characteristics is presented in [6] where suitable mutation operator for differential evolution (DE) is found by ant colony search. Gravitational search algorithm (GSA) is proposed in [7] to determine the optimal settings of control variables of the OPF problem in a power system. Artificial bee colony (ABC) algorithm is employed in [8, 9] as the main optimizer for optimal adjustments of the power system control variables of the OPF problem. The control variables involve both continuous and discrete variables. Multiple objective functions such as convex and non-convex fuel costs, voltage profile improvement, voltage stability enhancement and total emission cost are chosen for this highly constrained nonlinear non-convex optimization problem.

The design problem of the proposed system is formulated in an OPF framework [1] as an optimization problem, with an objective to minimize the generation cost of WECS and conventional types of generators while maintaining a satisfactory voltage profile during system operation.

II PROBLEM FORMULATION

To account for the intermittency of wind flow, a component of cost could be added to the system generation cost. Apart from the generation cost, this extra component is designed to mitigate the cost of operation during any condition of imbalance between available and utilized wind power.

Considering all these above facts, the problem is formulated as follows,

Minimize

$$\mathbf{F = F_1 + F_2} \quad (1)$$

In the above equation F_1 corresponds to cost of wind-thermal power generation, F_2 corresponds to cost of intermittent wind power generation.

The mathematical interpretation of the above components are described as

$$\mathbf{F_1 = \sum_{j}^{N_g} C_j(P_{gj})} \quad (2)$$

In this expression, subscript j denotes the thermal units and subscript k and w denote the wind units. The first term in F_1 is the cost of thermal power generation. These terms are explained as

$$\mathbf{C_j(P_{gj}) = a_j P_{gj}^2 + b_j P_{gj} + c_j} \quad (3)$$

where a_j, b_j, c_j are the cost coefficients of j^{th} thermal unit and P_{gj} is the power output of j^{th} generator. Details about the cost coefficients are given in Table.1.

$$\mathbf{F_2 = \sum_{k}^{N_w} [C_{wk}(P_{wk}) + C_{p,wk}(P_{wk,av} - P_{wk}) + C_{r,wk}(P_{wk} - P_{wk,av})]} \quad (4)$$

The different components of F_2 may be explained as below. The first term of F_2 is the cost of purchase of wind power from the wind power producer, second term is the cost due to under estimation of available wind power and third term is the cost due to over estimation of available wind power.

$$C_{wk}(P_{wk}) = d_k P_{wk} \tag{5}$$

Here d_k is the direct cost coefficient of the k^{th} wind generator and the scheduled power output of k^{th} wind unit is represented by P_{wk}. The cost due to under estimation of available wind power may be expressed by equation (6)

$$C_{p,wk}(P_{wk,av} - P_{wr}) = K_{Pk}(P_{w\,av} - P_{wk})$$
$$= K_{pk}\int_{P_{wk}}^{P_{ko}} (w - P_{wk}) f_w(w)\,dw \tag{6}$$

In (6), K_{Pk} is the penalty cost coefficient for the k^{th} wind generator and $f_w(w)$ is the wind power probability density function(PDF) [4], known as Weibull distribution function. P_{wk} , P_{ko}, $P_{w\,av}$ are respectively the scheduled, rated power and available wind power from k^{th} wind power generator. Cost of over estimation may be expressed as

$$C_{R\,wk}(P_{wk} - P_{wk\,av}) = K_{Rk}(P_{wk} - P_{w\,av})$$

$$= K_{Rk}\int_0^{P_{wk}} (P_{wk} - w) f_w(w)\,dw \tag{7}$$

The above mentioned objective function represented by (1) is subjected to the following constraints.

$$\sum_j^{N_g} P_{gj} + \sum_k^{N_w} P_{wk} = P_{loss} + P_{load} \tag{8}$$

$$\sum_j^{N_g} Q_{gj} + \sum_k^{N_w} Q_{wk} = Q_{loss} + Q_{load} \tag{9}$$

$$P_{gj}^{min} \le P_{gj} \le P_{gj}^{max} \tag{10}$$

$$Q_{gj}^{min} \le Q_{gj} \le Q_{gj}^{max} \tag{11}$$

$$V_j^{min} \le V_j \le V_j^{max} \tag{12}$$

$$P_{wk} \le P_{wk}^{max} \tag{13}$$

$$Q_{wk}^{min} \le Q_{wk} \le Q_{wk}^{max} \tag{14}$$

In the above expressions (8)-(14) the real and reactive power output of thermal generators are represented as P_{gj}, Q_{gj} respectively where as P_{wk}, Q_{wk} are the corresponding powers of wind powered units.

III IMPLEMENTATION OF OPTIMIZATION TECHNIQUES

3.1 Artificial Bee Colony Algorithm

Artificial bee colony algorithm (ABCA) is an optimization algorithm based on the intelligent foraging behavior of honeybee swarm [8,9]. The control variables involve both continuous and discrete variables. ABCA is a population-based algorithm developed by considering the notion that how honeybee swarm stumble on their food. The honeybee swarm in this algorithm is divided into two factions: worker bees and non-worker bees including onlooker bees and explorer bees. The onlooker bees are produced with certain intervals around the worker bees. If the produced onlooker bees find the best fitness value among all the reproduced bees are represented in the next iteration. The detailed flow chart with explanation can be referred from [9].

3.2 Hybrid Algorithm

The Hybrid Algorithm (HA) is synthesized by implementing the mutation strategies of GA along with a modified strategy of BFA that was first proposed in [16] and then applied in [2,3,4], so that the optimization efficiencies of both the algorithms may be further improved in some specific problems. The original version of BFA may be referred from [16]. The modified improved version of BFA is similar to the original algorithm, except some modifications, which are elaborated in [2]. The exhaustively explained steps involved in HA can be followed from [11]. In [11], a comparative analysis between HA and PSO has been done to demonstrate the effectiveness of HA. In a similar manner the competency of HA is tested with ABCA in this work to further analyze the behavior in a hybrid power generation system.

IV. SIMULATION, RESULTS AND DISCUSSION

For simulation of the work, the IEEE-30 bus test system [15] is considered. The system is modified by replacing conventional generators with wind farms located at fifth, eleventh and thirteenth bus. Each wind farm (WF) consists of several wind turbine, or specifically wind turbine generator (WTG). In this work, WF at bus number *5* consists of twenty WTG (each of 2.5 MW) having a total capacity of *50 MW*. Similarly WF at bus numbers11 and 13 each consist of seven WTG of *5 MW* capacities with a total capacity of *35 MW*. The system is modified by replacing conventional generators with wind farms located at fifth, eleventh and thirteenth bus. Each wind farm (WF) consists of several wind turbine coupled with doubly fed induction generators (DFIGs). For obtaining the optimum schedule, optimal power flow equations are solved to optimize objective function defined in previous section. Two different optimization techniques implemented on the objective function are examined for a comparative study. The optimal generation cost obtained with both HA and ABCA are depicted in Table.1.The generation cost coefficients of the thermal units are tabulated in Table-2. The total cost of generating power in the wind-thermal system is evaluated for the objective as specified in (1) and is optimized by applying HA and ABCA separately. The convergence characteristic obtained by GA and HA for the above objective function is illustrated in Fig. 1. From this, it can be seen that solutions obtained with the HA converges at 1966.12 \$/hr, where as ABCA has managed to converge at 1968.18 \$/hr.

Analysis of system operation from voltage security point of view has been done under normal operating condition during UE scenario. With the optimal generation schedule obtained with HA and ABCA separately, the system voltage profile has been portrayed in Fig.2. It clearly shows the superiority of HA optimized schedule over ABCA schedule in maintaining a better and improved voltage profile almost at every bus in the considered system.

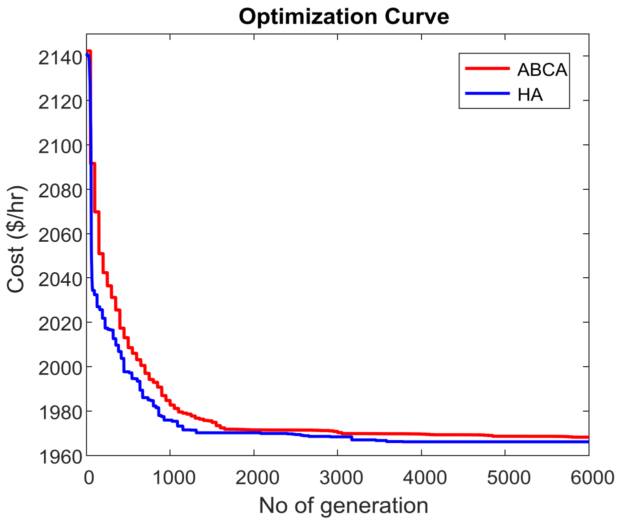

Fig.1.Convergence Characteristics

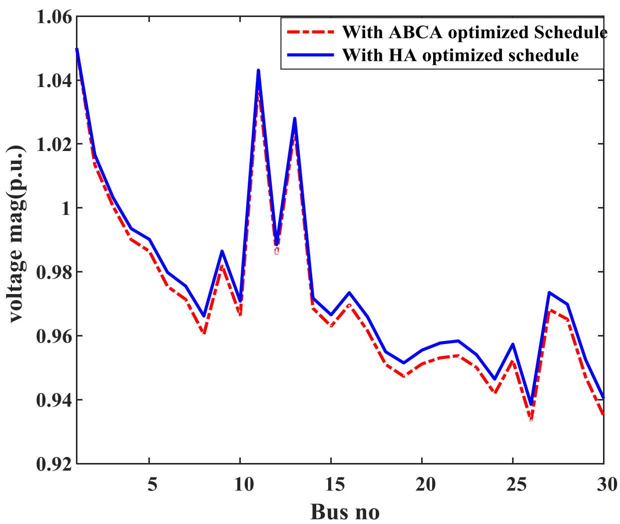

Fig.2. System voltage profile with HA and ABCA optimized schedule

From both the figures it may be depicted that substantial improvement in the system voltage and reduction of overall system operation cost has been achieved by the HA optimized generation schedule.

Generator No	**Cost Coefficients** a_t	b_t	c_t	Min limit (MW)	Max limit (MW)
1	0.00975	2.5	0	50	200
2	0.0175	1.75	0	20	80
3	0.0625	1.0	0	10	40

Table-1. Cost coefficients of thermal generating units.

V. CONCLUSION

Due to the unpredictability and intermittent nature of available wind power, it becomes very important to perform the generation scheduling in an intelligent and efficient manner, particularly during the underestimation scenario. This work not only focuses on minimization of generation cost but also aims to achieve an optimal voltage secure operation. In this regards, HA and ABCA techniques are implemented to the considered test system. In order to validate the effectiveness of the techniques, both the techniques are used to find the optimal operating schedule of IEEE-30 bus power system. The HA is found to be better than ABCA in terms of obtaining better convergence characteristics and providing an optimal generation scheduling which can give a satisfactory voltage secure system operation . Thus HA may give a promising solution to complex power system analysis and may a used as a decision supporting tool for power system operator in real time operation.

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