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Artificial Bee Colony Algorithm based Dynamic Optimal Power Flow of the Power System Including Wind Farm and Pumped Storage Hydro Unit

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Abstract

This paper presents an artificial intelligent based optimization technique with dynamic power flow model for a hybrid wind hydro pump storage unit (WHPSU) system which consists of fixed speed wind generator (FSWG) and a Pump Storage Hydro Unit (PSHU). Dynamic optimal power flow (DOPF) is a typical complex multi-constrained non-convex, non-linear, programming problem in hybrid wind hydro pump storage unit (WHPSU) system when considering the valve-point effect of conventional generators. It is more complicated when considering the reactive compensation of FSWG devices. Pump storage hydro unit (PSHU) is used in order to maintain the fixed/constant output power of wind farm. In this paper, an artificial bee colony based optimization algorithm (ABC) is proposed for solving the DOPF model. The proposed algorithm was tested on IEEE-30 bus system with six generator units. The results show that the artificial bee colony based optimization technique gives the better results than that of the particle swarm optimization (PSO) algorithm and genetic algorithm (GA). In addition with this, the results also show that the proposed optimization algorithm method is powerful and promising.

Keywords: Wind Power generation, Pump Storage Hydro Unit, Dynamic optimal power flow, reactive power compensation, artificial bee colony.

Introduction

Wind energy has become an increasing source of electrical energy production in recent years. For this reason, it is necessary to study the possible impact a wind power on the power network where it is connected. Wind turbine heavily rely on the ambient environmental conditions therefore produce unpredictable output power. PSHU is considered as the most suitable storage technology for achieving high wind penetration levels in medium or large autonomous power systems. The ability to balance demand with wind power, defines the wind capacity to manage positive and negative energy imbalances over the entire scheduling time. The pumped-storage plants provides the flexibility for the wind farm producer and to reduce the penalties for energy deviations over the entire scheduling time[4].Different types of modelling of wind farm are used for load flow analysis of power system. When a wind farm with asynchronous generation is to be included in a load flow analysis, the PQ and RX buses modelling are most commonly used [1].

Over the last few years, researchers have developed new techniques to improve the output controllability of wind parks and to facilitate its interaction with the energy power market. The operation of a wind park cooperating with two water reservoirs, involving a micro-hydroelectric power plant and water pump station. The objective was to store the energy generated by the wind park in low demand periods and sold it at high demand period [8, 9]. As described in [5-7] water pump/generation facilities are added to a wind park. This storage ability enables: 1) to store energy produced in low price periods, to be sold when the daily energy price is high and 2) to store energy in the reservoir in high wind speed periods to be used afterwards for filling wind-power gaps, as complement of the wind park production, helping in fulfilling any contractual commitment with the market or the grid.

Artificial Bee Colony Algorithm (ABC) is an optimization algorithm based on the intelligent foraging behaviour of honey bee swarm, proposed by Karaboga in 2005[10]. Attempts have been made in [11-13] to use ABC algorithm in power system problems. Basic OPF problem has been reported in [11] with the inclusion of both discrete and continuous control variables, whereas sizing and allocation of distributed generations have been attempted in [12-13].

In this paper, an operating policy is introduced for hybrid wind-hydro power stations which inject the significant wind power to the grid. The operation of pump storage hydro unit is based on the contractual agreement on the system operator [4].Pump storage hydro unit (PSHU) is used in order to maintain the fixed/constant output power of wind farm. An ABC based optimization technique was considered for solving dynamic optimal power flow of the power system equipped with a wind hydro pump storage unit (WPSHU) system which consists of FSWG and a PSHU. Dynamic optimal power flow (DOPF) is a typical complex multi-constrained non-convex, non-linear, programming problem in hybrid wind hydro pump storage unit (WHPSU) system when considering the valve-point effect of conventional generators. It is more complicated when considering the reactive compensation of FSWG devices. Finally the simulation was carried out in MATLAB version 7.8 environment and compared the results which are obtained from ABC, PSO and GA.

Problem Formulation

The power flow model for a WHPSU system is developed in order to calculate the injected wind power of the power system. WHPSU system always draws reactive power from the grid. In most cases, capacitors are connected in parallel to the generator to compensate the reactive power consumption. PQ model of wind farm i.e. steady state model of generator is shown in fig.1 is considered in order to calculate the consumed reactive power of the WHPSU.

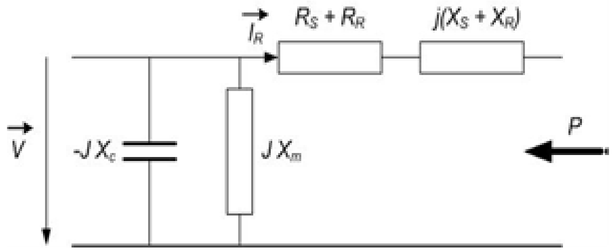

Figure 1: Induction machine steady- state model

The conservation of complex power theorem (Boucherot's theorem) is applied in this model to write the following expression for reactive power which is consumed by the machine [1].

$$Q=V^2\frac{X_c-X_m}{X_CX_m}+X\frac{V_2+2RP}{2(R^2+X^2)}-X\frac{\sqrt{(V^2+2RP)-4P^2(R^2+X^2)}}{2(R^2+X^2)} \quad (1)$$

$$Q \simeq V^2\frac{X_c-X_m}{X_CX_m}+\frac{X}{V^2}P^2 \quad (2)$$

Where V is the rated voltage, P is the real power (positive when injected into the grid), X is the sum of the stator and rotor leakage reactance, X_c is the reactance of the capacitors bank, and R is the sum of the stator and rotor resistances. In [1] the following expression is proposed for the calculation of real power of the WT.

$$P=\frac{1}{2}\rho AU^3C_P \quad (3)$$

Where A = rotor area, p = density of air, U = wind speed and C_P = power coefficient. The nominal parameters of the induction generator are given in appendix A.

Optimal Power Flow

Due to the unpredictable output of the wind power and load demands, it is difficult to research the DOPF in the power system including WHPSU system. According to the WHPSU system output power and the load forecasting curves in the planning horizon, the expectations of the dispatch interval can be calculated. The DOPF goal is to optimize a certain objective subject to several equality and inequality constraints. The problem can be mathematically modelled as follow

$$MinF(x,u) \tag{4}$$

Subject to:

$$g(x,u)=0 \tag{5}$$

$$h\min \leq h(x,u) \leq h\max \tag{6}$$

Where vector x denotes the state variables of a power system network that contains the slack bus real power output(P_{G1}), ramp rate (D_R/U_R), voltage magnitudes and phase angles of the load buses (V_{Lk}, θ_{LK}) and generator reactive power outputs Q_G. Vector u represents both integer and continuous control variables that consist of real power generation level (P_{GN}), voltage magnitudes (V_{GN}), transformer tap setting (T_K), and reactive power injections (Q_{CK}) due to volt-amperes reactive (VAR) compensation; i.e.,

$$u=\overbrace{P_{G2}.....P_{GN}, V_{G2}....V_{GN}}^{Continuous}, \overbrace{T_1...T_N, Q_{C1}.....Q_{CN}}^{discrete} \tag{7}$$

Objective function

The main objective of this paper is to determine the optimal parameter setting of the control variable in the power network to minimize fuel cost.

Fuel cost

$$F=\sum_{i=1}^{i=N}(a_i+b_iP_{Gi}+c_iP_{Gi}^2)\ \$/\mathrm{h} \tag{8}$$

Constraints

To minimization of the objective function is subject to a number of unit and system constraints as follows:

System power balance

$$P_{Gi}-P_{Di}-\sum_{j=1}^{n}|V_i||V_j||V_{ij}|\cos(\theta_{ij}-\delta_i+\delta_j)=0 \tag{9}$$

$$Q_{Gi}-Q_{Di}-\sum_{j=1}^{n}|V_i||V_j||V_{ij}|\sin(\theta_{ij}-\delta_i+\delta_j)=0 \tag{10}$$

The generators real and reactive power outputs

$$P_{Gi}^{\min} \leq P_{Gi} \leq P_{Gi}^{\max} \quad i=1......G_N \tag{11}$$

$$Q_{Gi}^{\min} \leq Q_{Gi} \leq Q_{Gi}^{\max} \quad i=1......G_N \tag{12}$$

The voltage magnitude at each bus in the network

$$V_i^{\min} \le V_i \le V_i^{\max} \quad i = 1......N \tag{13}$$

Ramping rate for each generators

$$\left\{ \max(P_{Gi}^{\min}, P_{Gi}^{t-1} - D_{R_t}\Delta T) \le P_{Gi}^{t} \le \min(P_{Gi}^{\max}, P_{Gi}^{t-1} + U_{R_t}\Delta T) \right\} \tag{14}$$

$P_{Gi}{}^{t}$ is the real power output of unit i at the t^{th} interval,$P_{Gi}{}^{t-1}$ is the real power output of unit i at the $t\text{-}1^{th}$ interval, U_{Rt} is the up-ramp limit of the i^{th} generator (in units of MW/time period), D_{Rt} is the down-ramp limit of the i^{th} generator (in units of MW/time-period) and ΔT is time interval.

The discrete transformer tap settings

$$T_i^{\min} \le T_i \le T_i^{\max} \quad i = 1......N \tag{15}$$

The discrete reactive power injection due to capacitor banks

$$Q_{Ci}^{\min} \le Q_{Ci} \le Q_{Ci}^{\max} \quad i = 1......C_N \tag{16}$$

Pump storage hydro unit

A pumped storage hydro-turbine is an energy storage device with water being recycled between an upper reservoir and a lower reservoir. In [4] the following expressions are proposed for the operation of WHPSU system.

$$V^t = V^{t-1} + \Delta T(\eta_P P_{WT}^t - \frac{P_{HL}^t}{\eta_G}) \quad t = 1to\frac{24}{\Delta T} \tag{17}$$

$$V^t = V^{Initial} \text{ for } t = 0 \tag{18}$$

$$V^t = V^{Final} \quad \text{for } t = \frac{24}{\Delta T} \tag{19}$$

$$\alpha P_{Min}^t \le P_{EL}^t \le P_{Max}^t \quad t = 1to\frac{24}{\Delta T} \tag{20}$$

$$0 \le \alpha \le 1 \tag{21}$$

$$0 \le P_{WL}^t \le P_W^t \quad t = 1to\frac{24}{\Delta T} \tag{22}$$

$$0 \le P_{WD}^t \le P_W^t \quad t = 1to\frac{24}{\Delta T} \tag{23}$$

$$0 \le P_{WP}^t \le P_{PSH} \quad t = 1to\frac{24}{\Delta T} \tag{24}$$

$$0 \le P_{HL}^t \le P_{PSH} \quad t = 1to\frac{24}{\Delta T} \tag{25}$$

$$V^{Min} \le V^t \le V^{Max} \quad t = 1to(\frac{24}{\Delta T} - 1) \tag{26}$$

where vector P_{EL} contains hourly active power delivered to the electricity market by WPSHU facility, vector P_{WL} contains hourly active power delivered to the network by the wind farm, vector P_{WP} contains hourly average active power consumed by the PSH unit to pump the water, vector P_{WD} contains hourly unutilized wind power (dump load), vector P_{HL} contains hourly active power produced by PSHU, vector P_W contains hourly available active power from the wind farm, vector V denotes hourly energy storage level in the reservoir, vectors P_{min} and P_{max} contain hourly values of minimum and maximum power output limits, respectively. Superscript *t in* aforesaid vectors indexes the time segment under consideration, α is a variable to represent a decrease factor in the output lower limit and ΔT is the duration of time segment. η_P and η_G are efficiencies associated with pumping and generation operations, respectively, by PSHU. $V^{Initial}$ and V^{Final} are initial and final energy levels, respectively of the reservoir, V_{Min} and V_{Max} are minimum and maximum energy levels, respectively, of the reservoir and P_{PSH} is the nominal capacity of PSHU.

Artificial Bee Colony Algorithm

In the ABC algorithm, the colony of artificial bees contains three groups of bees: employed bees, onlookers and scouts. A bee waiting on the dance area for making decision to choose a food source is called an onlooker and a bee going to the food source visited by itself previously is named an employed bee. A bee carrying out random search is called a scout. In the ABC algorithm, first half of the colony consists of employed artificial bees and the second half constitutes the onlookers. For every food source, there is only one employed bee. In other words, the number of employed bees is equal to the number of food sources around the hive. The employed bee whose food source is exhausted by the employed and onlooker bees becomes a scout. The main steps of the algorithm are given below:

Initial phase

A randomly distributed initial population (food source positions) of solution *i* (i=1,2 ,3........E_b) is generated where *i* signifies the size of population and E_b is the number of employed bees. Each solution X_i is a *D* dimensional vector, where *D* is the number of parameters to be optimized. The neighbour food-source position is created according to the following expression:

$$X_{i,j}^{new} = X_{i,j}^{old} + r*(X_{i,j}^{old} - X_{i,j}), k \neq i, \in (1,2....E_b) \quad (27)$$

When the food-source position has been abandoned, the employed bee associated with it becomes a scout. The scout produces a completely new food-source position as follows:

$$X_i^{j(new)} = \min X_i^j + r*(\max X_i^j - \min X_i^j) \quad (28)$$

Where equation (28) applies for all j parameters and r is a random number between [0,1].

Employed bees phase

The population is subjected to repeat the cycles of the search processes of the employed, After all employed bees complete the search process; they share the position information of the sources with the onlookers on the dance area. To sharing the information probability values are calculated for the solutions by means of their fitness values using the following equation.

$$P_i = \frac{f_{iti}}{\sum_{i=1}^{E_b} f_{iti}} \tag{29}$$

$$f_{iti} = \begin{cases} \dfrac{1}{1+f_i}, & f_i > 0 \\ 1+f, & f_i < 0_i \end{cases} \tag{30}$$

Where f_{iti} is the fitness value of a solution i, E_b is the total number of food source positions (solutions) or half of the colony size. The fitness values might be calculated using the above definition as expressed in (31).

Onlooker bees phase

Onlookers are placed onto the food source sites by using a fitness based selection technique, for example roulette wheel selection method.

Scout bees phase

Each onlooker evaluates the nectar information taken from all employed bees and then chooses a food source depending on the nectar amounts of sources. The sources abandoned are determined and new sources are randomly produced to be replaced with the abandoned ones by artificial scout.

Result and Discussion

The proposed algorithm was implemented in standard IEEE 30-bus test system with different loading condition over the scheduling time. A 4-hour planning horizon is considered for this study. The test system consists of six generating units and a WHPSU which are interconnected with 41 branches of a transmission network to serve the scheduling load which is shown in figure 2. The base case active and reactive power loads are 189.2 MW and 107.2 MVAR respectively [14].

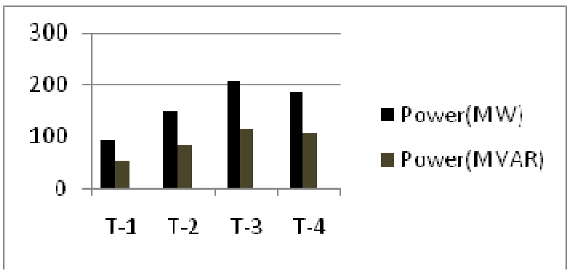

Figure 2: Load demand curve

The load distribution is assumed as 50%, 80% and 110% of the base load. The duration of scheduling interval (i.e. ΔT) is taken as 1 hour. The wind farm and pump storage limit data are taken from [4]. The generators cost coefficient and ramp limit data are taken from [3]. The wind farm was assumed to be allocated at bus 9 [3] which is the PQ bus of the transmission network. DOPF was carried out by means of ABC algorithm on IEEE 30 bus system at given scheduling period with different loading conditions and compared the results with PSO and GA which are shown in Table 2. Parameters of ABC algorithm are given in Appendix-B. The simulation results obtained from ABC algorithm are compared with that of the GA and PSO as shown in Table 2. From the results it is clearly seen that the value of total generation cost and losses obtained by dint of ABC algorithm was optimal than that of GA and PSO. Comparison of the simulation results after 100 trial runs are shown in below:-

Table 2.1: WHPSU power 8 MW

Control Variable	Result		
	GA	*PSO*	*ABC*
Wind	6.5	5.0	7
PG_1	25.16	25.32	26.66
PG_2	35.72	33.50	38.09
PG_{13}	16.69	17.14	16.84
PG_{22}	3.12	0	0
PG_{23}	3.58	8.44	3.26
PG_{27}	3.45	3.10	2.66
T_{11}	0.92	0.90	0.93
T_{12}	1.04	0.90	0.99
T_{15}	0.97	1.05	0.90
T_{36}	1.03	0.90	0.91
QC_5	6	39	13
QC_{24}	3	38	23
Cost	213.86	213.85	212.35
Losses	1.12	0.90	0.91

The simulation was carried out for 200 iterations. It has been observed that the efficiency of ABC algorithm is better than GA and PSO; it is obvious that the ABC algorithm was able to determine the minimum value of generation cost with slightly faster computational time than that of GA and PSO. Figure 4 shows the evolution of fitness value for one of the given period and it is also clearly shown that the ABC could effectively find the optimum solution before the maximum iteration was reached.

Table 2.2: WHPSU Power 5 MW

Control Variable	**Result**		
	GA	*PSO*	*ABC*
Wind	6.0	4.5	5.25
PG_1	37.00	38.22	37.78
PG_2	50.48	51.19	51.04
PG_{13}	20.43	20.97	20.79
PG_{22}	13.27	10.80	10.80
PG_{23}	12.11	12.02	12.11
PG_{27}	14.69	14.68	15.32
T_{11}	0.92	1.05	1.01
T_{12}	0.92	0.90	1.02
T_{15}	0.96	1.05	1.0
T_{36}	0.93	0.90	1.04
QC_5	18	22	6
QC_{24}	17	23	1
Cost	414.89	414.74	414.72
Losses	1.62	1.52	1.48

Table 2.3: WHPSU power 6 MW

Control Variable	**Result**		
	GA	*PSO*	*ABC*
Wind	8.0	4.5	6.0
PG_1	49.42	49.04	49.67
PG_2	63.62	64.68	65.06
PG_{13}	25.40	24.89	24.71
PG_{22}	23.71	21.60	21.6
PG_{23}	19.41	22.20	21.72
PG_{27}	23.55	22.52	22.17
T_{11}	0.94	1.05	1.03
T_{12}	0.93	0.90	1.01
T_{15}	0.95	1.05	1.0
T_{36}	0.90	1.05	1.04
QC_5	22	20	5
QC_{24}	10	32	38
Cost	629.49	629.44	629.34
Losses	2.99	2.81	2.81

Table 2.4: WHPSU Power 9 MW

Control Variable	Result		
	GA	*PSO*	*ABC*
Wind	3.5	5.75	7.75
PG_1	42.29	43.12	41.15
PG_2	56.04	54.83	54.52
PG_{13}	22.25	21.70	22.08
PG_{22}	29.11	31.41	31.94
PG_{23}	15.10	15.79	15.97
PG_{27}	17.84	15.76	16.88
T_{11}	0.94	1.05	1.05
T_{12}	0.94	1.05	1.03
T_{15}	0.94	0.90	0.97
T_{36}	0.94	1.05	0.98
QC_5	2	37	28
QC_{24}	13	38	13
Cost	540.72	540.52	540.50
Losses	2.43	2.41	2.34

Conclusion

This paper presents an ABC based optimization method for dynamic optimal power flow of the power system which has been tested on IEEE -30 bus system including wind farm and pumped storage hydro unit. The simulation result was carried out in MATLAB environment. It has been observed that the simulation results obtained from ABC algorithm gives the better results than that of PSO and GA. It can also be noticed that the ABC algorithm converge towards the better solution slightly faster than PSO and GA.

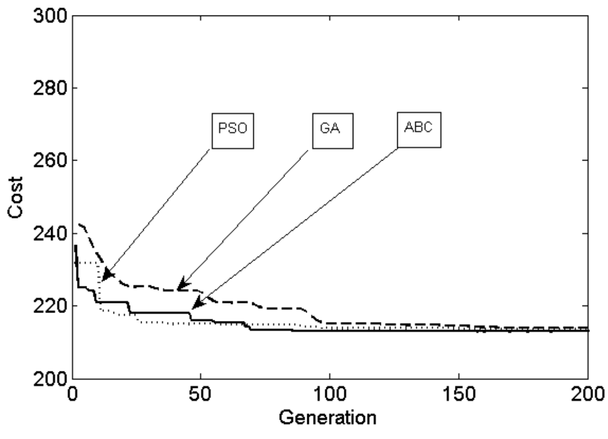

Figure 4: Evolution of fitness value

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Appendix

Parameters of the induction generator

$R_S = 0.00708\Omega$, $X_1 = 0.07620\Omega$ $X_m=3.4497\Omega$, $X_C=3.496\Omega$, $X_R=0.23289\Omega$, $R_R=0.00759\Omega$ and Rated voltage= 660V.

Parameters of the ABC

No. of Scout Bees	100
No. of sites selected for neighbourhood search	60
No. of bee recruited for the best sites	20
No. of reaming bees	10
No. of iterations	200