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Reduction of Active Power Loss by Incorporated Cuckoo Search Algorithm

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Abstract
This paper projects Incorporated Cuckoo Search (ICS) algorithm for solving optimal reactive power problem. In this work quantum computing principles has been incorporated with cuckoo search algorithm to improve the exploration & exploitation. The contribution consists in defining an appropriate representation scheme in the cuckoo search algorithm that allows applying successfully in reactive quantum computing principles like qubit representation, superposition of states, measurement, and interference. This hybridization improves the capabilities of the search process. In order to evaluate the efficiency of the proposed algorithm it has been tested in standard IEEE 118 & practical 191 bus test systems and compared to other algorithms. Simulation results show that Incorporated Cuckoo Search (ICS) algorithm is more efficient in reducing the real power loss and control variables are within the limits.

Key words
Transmission, Real Power Loss, Cuckoo Search, Quantum Computing.

1. Introduction

Optimal Reactive Power Problem is subject to number of uncertainties and at least in the best case to uncertainty parameters given in the demand and about the availability equivalent amount of shunt reactive power compensators. Optimal reactive power dispatch plays a major role for the operation of power systems, and it should be carried out in a proper manner, such that system reliability is not got affected. The main objective of the optimal reactive power dispatch is to maintain the level of voltage and reactive power flow within the specified limits under various operating conditions and network configurations. By utilizing a number of control tools such as switching of shunt reactive power sources, changing generator voltages or by adjusting transformer tap-settings the reactive power dispatch can be done. By doing optimal adjustment of these controls in different levels, the redistribution of the reactive power would minimize transmission losses. This procedure forms an optimal reactive power dispatch problem and it has a major influence on secure and economic operation of power systems. Various mathematical techniques like the gradient method [1,2] Newton method [3]and linear programming [4-7] have been adopted to solve the optimal reactive power dispatch problem. Both the gradient and Newton methods has the difficulty in handling inequality constraints. If linear programming is applied then the input- output function has to be expressed as a set of linear functions which mostly lead to loss of accuracy. The problem of voltage stability and collapse play a major role in power system planning and operation [8]. Enhancing the voltage stability, voltage magnitudes within the limits alone will not be a reliable indicator to indicate that, how far an operating point is from the collapse point. The reactive power support and voltage problems are internally related to each other. This paper formulates by combining both the real power loss minimization and maximization of static voltage stability margin as the objectives. Global optimization has received extensive research attention, and a great number of methods have been applied to solve this problem. Evolutionary algorithms such as genetic algorithm have been already proposed to solve the reactive power flow problem[9,10].Evolutionary algorithm is a heuristic approach used for minimization problems by utilizing nonlinear and non-differentiable continuous space functions. In [11], by using Genetic algorithm optimal reactive power flow has been solved, and the main aspect considered is network security maximization. In [12] is proposed to improve the voltage stability index by using Hybrid differential evolution algorithm. In [13] Biogeography Based algorithm proposed to solve the reactive power dispatch problem. In [14] a fuzzy based method is used to solve the optimal reactive power scheduling method and it minimizes real power loss and maximizes Voltage Stability Margin. In [15] an improved evolutionary programming is used to solve the optimal reactive power dispatch problem. In [16] the optimal reactive power flow problem is solved by integrating a genetic algorithm with a nonlinear interior point method. In [17] a standard algorithm is used to solve ac-dc optimal reactive power flow model with the generator capability limits .In [18] proposed a two-step approach to evaluate Reactive power reserves with respect to operating constraints and voltage stability. In [19] a programming based proposed approach used to solve the optimal reactive power dispatch problem. In [20] is presented a probabilistic algorithm for optimal reactive power provision in hybrid electricity markets with uncertain loads. This paper projects

Incorporated Cuckoo Search (ICS) algorithm for solving optimal reactive power problem. The proposed algorithm combines Cuckoo Search algorithm [21, 22] and quantum [25-30] computing in new one. The cuckoo's behaviour and the mechanism of Levy flights [23, 24] have leading to design of an efficient inspired algorithm performing optimization search. In this work quantum computing principles has been incorporated with cuckoo search algorithm to improve the exploration & exploitation. The contribution consists in defining an appropriate representation scheme in the cuckoo search algorithm that allows applying successfully in reactive quantum computing principles like qubit representation, superposition of states, measurement, and interference. This hybridization improves the capabilities of the search process. In order to evaluate the efficiency of the proposed algorithm it has been tested in standard IEEE 118 & practical 191 bus test systems and compared to other algorithms. Simulation results show that Incorporated Cuckoo Search (ICS) algorithm is more efficient in reducing the real power loss and control variables are within the limits.

2. Problem Formulation

The optimal power flow problem is treated as a general minimization problem with constraints, and can be mathematically written in the following form:

Minimize f(x, u) (1)

Subject to g(x,u)=0 (2)
and
$h(x, u) \leq 0$ (3)

Where f(x,u) is the objective function. g(x.u) and h(x,u) are respectively the set of equality and inequality constraints. x is the vector of state variables, and u is the vector of control variables.

The state variables are the load buses (PQ buses) voltages, angles, the generator reactive powers and the slack active generator power:

$$x = \left(P_{g1}, \theta_2, .., \theta_N, V_{L1}, ., V_{LNL}, Q_{g1}, .., Q_{gng}\right)^T \quad (4)$$

The control variables are the generator bus voltages, the shunt capacitors/reactors and the transformers tap-settings:

$$u = \left(V_g, T, Q_c\right)^T \quad (5)$$

or

$$u = \left(V_{g1}, \ldots, V_{gng}, T_1, .., T_{Nt}, Q_{c1}, .., Q_{cNc}\right)^T \quad (6)$$

Where ng, nt and nc are the number of generators, number of tap transformers and the number of shunt compensators respectively.

3. Objective Function

3.1 Active power loss

The objective of the reactive power dispatch is to minimize the active power loss in the transmission network, which can be described as follows:

$$F = PL = \sum_{k \in Nbr} g_k \left(V_i^2 + V_j^2 - 2V_iV_j cos\theta_{ij}\right) \quad (7)$$

or

$$F = PL = \sum_{i \in Ng} P_{gi} - P_d = P_{gslack} + \sum_{i \neq slack}^{Ng} P_{gi} - P_d \quad (8)$$

where g_k : is the conductance of branch between nodes i and j, Nbr: is the total number of transmission lines in power systems. P_d: is the total active power demand, P_{gi}: is the generator active power of unit i, and P_{gsalck}: is the generator active power of slack bus.

3.2 Voltage profile improvement

For minimizing the voltage deviation in PQ buses, the objective function becomes:

$$F = PL + \omega_v \times VD \quad (9)$$

where ω_v: is a weighting factor of voltage deviation.

VD is the voltage deviation given by:

$$VD = \sum_{i=1}^{Npq} |V_i - 1| \quad (10)$$

3.3 Equality Constraint

The equality constraint g(x,u) of the ORPD problem is represented by the power balance equation, where the total power generation must cover the total power demand and the power losses:

$$P_G = P_D + P_L \quad (11)$$

This equation is solved by running Newton Raphson load flow method, by calculating the active power of slack bus to determine active power loss.

3.4 Inequality Constraints

The inequality constraints h(x,u) reflect the limits on components in the power system as well as the limits created to ensure system security. Upper and lower bounds on the active power of slack bus, and reactive power of generators:

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$$P_{gslack}^{min} \leq P_{gslack} \leq P_{gslack}^{max} \quad (12)$$

$$Q_{gi}^{min} \leq Q_{gi} \leq Q_{gi}^{max}, i \in N_g \quad (13)$$

Upper and lower bounds on the bus voltage magnitudes:

$$V_i^{min} \leq V_i \leq V_i^{max}, i \in N \quad (14)$$

Upper and lower bounds on the transformers tap ratios:

$$T_i^{min} \leq T_i \leq T_i^{max}, i \in N_T \quad (15)$$

Upper and lower bounds on the compensators reactive powers:

$$Q_c^{min} \leq Q_c \leq Q_C^{max}, i \in N_C \quad (16)$$

Where N is the total number of buses, N_T is the total number of Transformers; N_c is the total number of shunt reactive compensators.

4. Quantum Computing

Quantum computing is a new theory which has emerged as a result of merging computer science and quantum mechanics. The qubit is the smallest unit of information stored in a two-state quantum computer. Contrary to classical bit which has two possible values, either 0 or 1, a qubit will be in the superposition of those two values. The state of a qubit can be represented by using the bracket notation:

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle \quad (17)$$

Where $|\Psi\rangle$ denotes more than a vector $\vec{\psi}$ in some vector space. $|0\rangle$ and $|1\rangle$ represent the classical bit values 0 and 1 respectively; a and b are complex numbers such that:

$$|a|^2 + |b|^2 = 1 \quad (18)$$

a and b are complex number that specify the probability amplitudes of the corresponding states. When we measure the qubit's state we may have '0' with a probability $|a|^2$ and we may have '1' with a probability$|b|^2$. A system of m-qubits can represent 2mstates at the same time. Quantum computers can perform computations on all these values at the same time. It is this exponential growth of the state space with the number of particles that suggests exponential speed-up of computation on quantum computers over classical computers.

5. Cuckoo Search Algorithm

One of the recent developed bio inspired algorithms is the Cuckoo Search (CS) which is based on style life of Cuckoo bird. The Cuckoo Search is based on the following three idealized rules:

• Each cuckoo lays one egg at a time, and dumps it in a randomly chosen nest;

• The best nests with high quality of eggs (solutions) will carry over to the next generations;

• The number of available host nests is fixed, and a host can discover an alien egg with a probability pa ∈ [0, 1]. In this case, the host bird can either throw the egg away or abandon the nest so as to build a completely new nest in a new location.

The last assumption can be approximated by a fraction pa of the n nests being replaced by new nests (with new random solutions at new locations). The generation of new solutions x(t+1) is done by using a Levy flight (eq.19). Levy flights essentially provide a random walk while their random steps are drawn from a Levy distribution for large steps which has an infinite variance with an infinite mean (eq.20). Here the consecutive jumps/steps of a cuckoo essentially form a random walk process which obeys a power-law step-length distribution with a heavy tail.

$$x_i^{t+1} = x_i^t + \alpha \oplus \text{Lévy}(\lambda) \quad (19)$$

$$\text{Lévy} \sim u = t^{-\lambda} \quad (20)$$

Where $\alpha > 0$ is the step size which should be related to the scales of the problem of interest. Generally we take $\alpha = O(1)$. The product ⊕ means entry-wise multiplications. This entry-wise product is similar to those used in PSO, but here the random walk via Levy flight is more efficient in exploring the search space as its step length is much longer in the long run.

The proposed cuckoo search algorithm can be described as follow:

Objective function f(x), x =(x1,.., x_d)T ;
Initial a population of n host nests xi (i = 1, 2, ..., n);
While (t < Max Generation) or (stop criterion);
Get a cuckoo (say i) randomly by Levy flights;
Evaluate its quality/fitness F_i;
Choose a nest among n (say j) arbitrarily;
If ($F_i > F_j$),
Replace j by the new solution;
End
Abandon a fraction (pa) of worse nests

Build new ones at new locations via Levy flights;
Keep the best solutions (or nests with quality solutions);
Rank the solutions and find the current best;
End while

6. Incorporated Cuckoo Search (ICS) algorithm

The proposed Incorporated Cuckoo Search (ICS) algorithm incorporate the quantum computing principles such as qubit representation, measure operation and quantum mutation, with the core of cuckoo search algorithm. This architecture contains three essential modules. The first module contains a quantum representation of cuckoo swarm. The particularity of quantum inspired cuckoo search algorithm stems from the quantum representation it adopts which allows representing the superposition of all potential solutions for a given problem. Moreover, the generation of a new cuckoo depends on the probability amplitudes a and b of the qubit function Ψ (eq.24). The second module contains the objective function and the selection operator. The selection operator is similar to the elitism strategy used in genetic algorithms. Finally, the third module, which is the most important, contains the main quantum cuckoo dynamics. This module is composed of 4 main operations inspired from quantum computing and cuckoo search algorithm: Measurement, Mutation, Interference, and Levy flights operations. Incorporated Cuckoo Search (ICS) algorithm uses these operations to evolve the entire swarm through generations.

In terms of quantum computing, each binary solution is represented as a quantum register of length N (N is the solution size).Each column represents a single qubit and corresponds to the binary digit 1 or 0. For each qubit, a binary value is computed according to its probabilities$|a_i|^2$ and $|b_i|^2$, which can be interpreted as the probabilities to have respectively 0 or 1. Consequently, all potential solutions can be represented by a Quantum Vector QV that contains the superposition of all possible solutions. This quantum vector can be viewed as a probabilistic representation of all the problem solutions. It plays the role of a quantum cuckoo in the Incorporated Cuckoo Search (ICS) algorithm. A quantum representation (Fig1) offers a powerful way to represent the solution space and reduces consequently the required number of cuckoos. Only one cuckoo is needed to represent the entire swarm.

$$\left\langle \begin{matrix} a_1 \\ b_1 \end{matrix} \middle| \begin{matrix} a_2 \\ b_2 \end{matrix} \middle| \begin{matrix} ..a_n \\ ..b_n \end{matrix} \right\rangle$$

Fig.1. Quantum representation of the cuckoo solution

Quantum Operators

We have integrated in the cuckoo search algorithm, some of quantum operations. This integration helps to increase the optimization capacities of the cuckoo search.

Measurement

The binary values for a qubit are computed according to its probabilities$|a_i|^2$ and $|b_i|^2$. This operation is accomplished as follows: for each qubit, we generate a random number Pr between 0 and 1; the value of the corresponding bit is 1 if the value$|b_i|^2$ is greater than Pr, and otherwise the bit value is 0. Moreover, the measurement operation can be seen also as a diversification operator. Indeed, two successive measurements do not give necessarily the same solution which increases the diversification capacities of our approach.

Quantum Interference

This operation amplifies the amplitude of the best solution and decreases the amplitudes of the bad ones. It primarily consists in moving the state of each qubit in the direction of the corresponding bit value in the best solution in progress. The operation of interference is useful to intensify research around the best solution and it plays the role of local search method.

Mutation Operator

This operator is inspired from the evolutionary mutation. It allows moving from the current solution to one of its neighbours. This operator allows exploring new solutions and thus enhances the diversification capabilities of the search process. In each generation, the mutation is applied with some probability.

Firstly, a swarm of p host nest is created at random positions to represent all possible solutions. The algorithm progresses through a number of generations according to the Incorporated Cuckoo Search (ICS) algorithm dynamics. During iteration's, the following main tasks are performed. A new cuckoo is built using the Levy flights operator followed by the quantum mutation which is applied with some probability. The next step is to evaluate the current cuckoo. For that, we apply the measure operation in order to get a binary solution which represents a potential solution. After this step, we apply the interference operation according to the best current element. We replace some worst nests by the current cuckoo if it is better or by new random nests generated by the Levy flight. The selection phase in Incorporated Cuckoo Search

(ICS) algorithm of the best nests or solutions is comparable to some form of elitism selection used in genetic algorithms, which ensures the best solution is kept always in the next iteration. Finally, the global best solution is then updated if a better one is found and the whole process is repeated until reaching a stopping criterion. The particularity of Incorporated Cuckoo Search (ICS) algorithm stems from the quantum representation it adopts which allows representing the superposition of all potential solutions for a given problem. Moreover, the position of a nest depends on the probability amplitudes a and b of the qubit function. The probabilistic nature of the quantum measure offers a good diversity to the cuckoo search algorithm, while the interference operation helps to intensify the search around the good solutions.

Construct an initial population of p host nests
While (stop criterion)
Apply Levy flights operator to get cuckoo randomly;
Apply arbitrarily a quantum mutation
Apply measurement operator;
Evaluate the quality/fitness of this cuckoo;
Apply Interference operator;
Replace some nests among n randomly by the new solution according to its fitness;
A fraction (pa) of the worse nests is abandoned and new ones are built via Levy flights;
Keep the best solutions (or nests with quality solutions);
Rank the solutions and find the current best;
End while

7. Simulation Results

At first Incorporated Cuckoo Search (ICS) algorithm has been tested in standard IEEE 118-bus test system [31].The system has 54 generator buses, 64 load buses, 186 branches and 9 of them are with the tap setting transformers. The limits of voltage on generator buses are 0.95 -1.1 per-unit., and on load buses are 0.95 -1.05 per-unit. The limit of transformer rate is 0.9 -1.1, with the changes step of 0.025. The limitations of reactive power source are listed in Table 1, with the change in step of 0.01.

Table 1. Limitation of reactive power sources

BUS	5	34	37	44	45	46	48
QCMAX	0	14	0	10	10	10	15
QCMIN	-40	0	-25	0	0	0	0
BUS	74	79	82	83	105	107	110
QCMAX	12	20	20	10	20	6	6
QCMIN	0	0	0	0	0	0	0

The statistical comparison results of 50 trial runs have been list in Table 2 and the results clearly show the better performance of proposed Incorporated Cuckoo Search (ICS) algorithm.

Table 2. Comparison results

Active power loss (p.u)	**BBO [32]**	**ILSBBO/ strategy 1 [32]**	**ILSBBO/ strategy 1 [32]**	**Proposed ICS**
Min	128.77	126.98	124.78	110.86
Max	132.64	137.34	132.39	115.04
Average	130.21	130.37	129.22	112.58

Then the Incorporated Cuckoo Search (ICS) algorithm has been tested in practical 191 test system and the following results have been obtained. In Practical 191 test bus system – Number of Generators = 20, Number of lines = 200, Number of buses = 191 Number of transmission lines = 55. Table 3 shows the optimal control values of practical 191 test system obtained by ICS method. And table 4 shows the results about the value of the real power loss by obtained by Incorporated Cuckoo Search (ICS) algorithm.

Table 3. Optimal Control values of Practical 191 utility (Indian) system by ICS method

VG1	1.10		VG 11	0.90
VG 2	0.74		VG 12	1.00
VG 3	1.01		VG 13	1.00
VG 4	1.01		VG 14	0.90
VG 5	1.10		VG 15	1.00
VG 6	1.10		VG 16	1.00

VG 7	1.10		VG 17	0.90
VG 8	1.01		VG 18	1.00
VG 9	1.10		VG 19	1.10
VG 10	1.01		VG 20	1.10

T1	1.00		T21	0.90		T41	0.90
T2	1.00		T22	0.90		T42	0.90
T3	1.00		T23	0.90		T43	0.91
T4	1.10		T24	0.90		T44	0.91
T5	1.00		T25	0.90		T45	0.91
T6	1.00		T26	1.00		T46	0.90
T7	1.00		T27	0.90		T47	0.91
T8	1.01		T28	0.90		T48	1.00
T9	1.00		T29	1.01		T49	0.90
T10	1.00		T30	0.90		T50	0.90
T11	0.90		T31	0.90		T51	0.90
T12	1.00		T32	0.90		T52	0.90
T13	1.01		T33	1.01		T53	1.00
T14	1.01		T34	0.90		T54	0.90
T15	1.01		T35	0.90		T55	0.90
T19	1.02		T39	0.90			
T20	1.01		T40	0.90			

Table 4. Optimum real power loss values obtained for practical 191 utility (Indian) system by ICS method.

Real power Loss (MW)	ICS
Min	140.862
Max	145.486
Average	142.824

8. Conclusion

In this paper Incorporated Cuckoo Search (ICS) algorithm successfully solved optimal reactive power problem. The contribution consists in defining an appropriate representation scheme in the cuckoo search algorithm that allows applying successfully in reactive quantum computing principles like qubit representation, superposition of states, measurement, and interference. This hybridization improves the capabilities of the search process. In order to evaluate the efficiency of the proposed algorithm it has been tested in standard IEEE 118 & practical 191 bus test systems and compared to other algorithms. Simulation results show that Incorporated Cuckoo Search (ICS) algorithm is more efficient in reducing the real power loss and control variables are within the limits.

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