Hybrid Solar Gas Reliability Optimization using Cat Swarm Optimization under Performance and Cost Constraints

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Abstract—**Global warming and resource depletion are really affecting us in a lot of ways Solar radiation is a promising source of renewable energy because it is abundant and the technologies to harvest it are quickly improving. However, solar power has a number of problems for implementation; the solar energies mainly depend upon sun availability and the changing climate. The focus on hybrid generation system increases the availability of power generation system by reducing the dependence on environment parameter. The purpose of this paper is concerned with the use of cat swarm (CS) meta-heuristic optimization method to solve the problem of hybrid power system design optimization. We consider the case where redundant electrical components are chosen to achieve desirable level of reliability. To allow fast estimation, a universal moment generating function UMGF and cat swarm CS are applied. An illustrative example is presented.**

Keywords-reliability; cat swarm ; universal generating function; optimization.

INTRODUCTION (HEADING 1)

Due to the increasing concern about the environment and the depletion of natural resources such as fossil fuels, much research is now focused on obtaining new environ-mentally friendly sources of power. To preserve our planet for the future generations, natural renewable sources are being closely studied and harvested for our energy needs. In recent years, concerns about fuel costs, environmental degradation and climate change have prompted consideration of alternative methods for electrical power generation [1]. It is argued that solar thermal technology offers an environmentally sensible alternative to the traditional clean coal" generation methods of recent past". Over the past years the alternative energy sources have been taking over higher and higher share in energy production. Solar energy is environmentally friendly, inexhaustible, safe, and capable of supplying substantial amounts of power [2].

The reliability aspects of utilizing renewable energy sources have largely been ignored in the past due to relatively insignificant contribution of these sources in major power systems and consequently due to the lack of appropriate techniques [3]. A relatively high penetration of these energy sources can create significant impacts on cost and reliability.

This paper describes the use of cat swarm optimization to solve the allocation problem involve the selection of the solar and gas units, transformers and lines for the appropriate levels of redundancy, the main aim is to maximize system reliability or minimize investment cost of series-parallel topology, given topology constraints (performance and cost). The reliable performance of the system for predefined missions under various constraints is very important in many industrial applications. The system redundancy, addressed in this paper is a common representation for many system design problems. The allocation devices method of system reliability discussed here consists in selecting the optimal solution in the context of reliability optimization of electrical network analysis. Given the overall restrictions on the system performance Ξ and cost C_0, the problem is to determine which topology alternative to select with the specified level of electrical device reliability, and what's kind of device to use in order to achieve the maximum system reliability.

In this paper, the objective is to adapt a new meta- heuristic CSA which include a modern technique (Ushakov technique) to select and evaluate the best configurations with maximal reliability met the cost and performance levels constraints.

II. PROBLEM FORMULATION

Let consider a series-parallel electrical power system containing n subsystems $i = 1, 2, \ldots, n$ in series arrangement as represented in Fig.1. Every subsystem i contain a number of different devices connected in parallel. For each subsystem i, there are a number of device versions available in the market. For each subsystem i, devices are characterized according to their version v by their performance (Ξ_{iv}), availability (A_{iv}), and cost (C_{iv}). The topology of subsystem i can be defined by the numbers of parallel devices (of each version) k_{iv} for $1 \leq v \leq V_i$, where V_i is a number of versions available for device of type i.

The entire system topology is defined by the vectors $k_i = \left\{ k_{iv_i} \right\}$ ($1 \leq i \leq n, 1 \leq v \leq V_i$). For a given set of vectors $k_1, k_2, \ldots, k_n$ the total cost of the system can be calculated as:

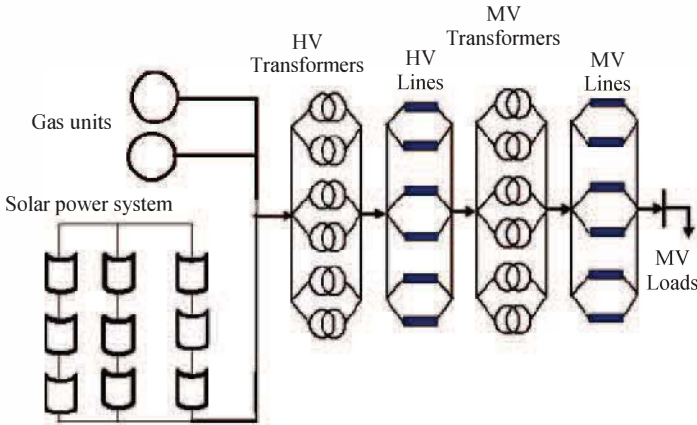$$C = \sum_{i=1}^{n} \sum_{v=1}^{V_i} k_{iv} C_{iv} \qquad (1)$$

Figure 1: Series-parallel power system structure

The multi-states reliability power system optimization problem can be formulated as follows: find the topology corresponding to the maximal reliability system $k_1, k_2, \ldots, k_n$, such that the corresponding performance exceeds or equal the specified performance Ξ_0 and cost less than the given cost C_0. That is, (see details in section IV)

Maximize

$$\begin{cases} \left\langle \sum_{i=1}^{n} \sum_{j=1}^{m} P_i Q_j z^{a_i + b_j} \right\rangle z^{-W} \\ \otimes \\ \left\langle \sum_{i=1}^{n} \sum_{j=1}^{m} P_i Q_j z^{\min\{a_i, \ b_j\}} \right\rangle z^{-W} \end{cases} \qquad (2)$$

Subject to

$$\begin{cases} \bullet \ \sum_{i=1}^{n} \sum_{v=1}^{V_i} k_{iv} C_{iv} \leq C_0 \\ \bullet \ \Xi^{\min\{a_i, \ b_j\}} \geq \Xi_0 \end{cases} \qquad (3)$$

The parameters a_i and b_j are physically interpreted as the performances of the two devices. n and m are numbers of possible performance levels for these devices. P_i and Q_j are steady-state probabilities of possible performance levels for devices.

In electric power systems, reliability is considered as a measure of the ability of the system to meet the load demand (W), i.e., to provide an adequate supply of electrical energy (Ξ). This definition of the reliability index is widely used for power systems: see e.g., [4][5]; and [6][7]. The Loss of Load Probability index (LOLP) is usually used to estimate the reliability index in [8]. This index is the overall probability that the load demand will not be met. Thus, we can write $A = Proba(\Xi \geq W)$ and the LOLP$= 1-A$. This reliability index depends on consumer demand W.

For reparable multi-state system, a multi-state steady-state availability E is used as $Probab(\Xi \geq W)$. In the steady-state the distribution of states probabilities is given by equation (4), while the MSS stationary reliability is formulated by equation (5):

$$P_j = \lim_{t \to \infty} [Proba(\Xi(t) = \Xi_j)] \qquad (4)$$

$$E = \sum_{\Sigma_j \ \Xi_j \geq W} P_j \qquad (5)$$

If the operation period T is divided into M intervals (with durations $T_1, T_2, \ldots, T_M$) and each interval has a required demand level ($W_1, W_2, \ldots, W_M$, respectively), then the generalized multi-state system reliability index A is:

$$A = \frac{1}{\sum_{j=1}^{M} T_j} \sum_{j=1}^{M} Proba(\Xi \geq W_j) \ T_j \qquad (6)$$

We denote by W and T the vectors $\left\{ W_j \right\}$ and $\left\{ T_j \right\}$ ($1 \leq j \leq M$), respectively. Then the reliability A is a function of $k_1, k_2, \ldots, k_n$, W and T. In the case of electrical power system, the vectors W and T define the cumulative load curve (consumer demand). In general, this curve is known for every power system.

IV. RELIABILITY ESTIMATION BASED ON USHAKOV METHOD

The last few years have seen the appearance of a number of works presenting various methods of quantitative estimation of systems consisting of devices that have a range of working levels in [4] [5]. Usually one considers reducible

systems. In general forms the series connection, the level of working is determined by the worst state observed for any one of the devices, while for parallel connection is determined by the best state. However, such the approach is not applicable for the majority of real systems.

In this paper the procedure used is based on the universal z-transform, which is a modern mathematical technique introduced in [6] [7]. This method, convenient for numerical implementation, is proved to be very effective for high dimension combinatorial problems. In the literature, the universal z-transform is also called Universal Multi-state Generating Function (UMGF) or simply u-transform [8] [9]. The UMGF extends the widely known ordinary moment generating function. The UMGF of a discrete random variable Ξ is defined as a polynomial:

$$u(z) = \sum_{j=1}^{J} P_j z^{\Xi_J} \quad (7)$$

Where the variables Ξ has J possible values and P_J is the probability that Ξ is equal to Ξ_j. The probabilistic characteristics of the random variable Ξ can be found using the function $u(z)$ [10] [11]. In particular, if the discrete random variable Ξ is the MSS stationary output performance, the availability A is given by the probability $Proba(\Xi \geq W)$ which can be defined as follows:

$$Proba(\Xi \geq W) = \Phi\left(u(z)z^{-W}\right) \quad (8)$$

Where Φ is a distributive operator defined by expressions (9) and (10):

$$\Phi(Pz^{\sigma - W}) = \begin{cases} P, & if\ \sigma \geq W \\ 0, & if\ \sigma < W \end{cases} \quad (9)$$

$$\Phi\left(\sum_{j=1}^{J} P_j z^{\Xi_j - W}\right) = \sum_{j=1}^{J} \Phi\left(P_j z^{\Xi_j - W}\right) \quad (10)$$

It can be easily shown that equations (9)–(10) meet condition $Proba(\Xi \geq W) = \sum_{\Xi_j \geq W} P_j$. By using the operator Φ, the coefficients of polynomial $u(z)$ are summed for every term with $\Xi_j \geq W$, and the probability that Ξ is not less than some arbitrary value W is systematically obtained [12].

Parallel devices: Let consider a system device m containing J_m devices connected in parallel. The total performance of the parallel system is the *sum* of performances of all its devices. In power systems, the term capacity is usually used to indicate the quantitative performance measure of an device in [13] [14]. Examples: generating capacity for a generator, carrying capacity for an electric transmission line, etc. Therefore, the total performance of the parallel unit is the sum of capacity (performances) in [15] [16]. The u-function $u_p(z)$ of MSS

device m containing J_m parallel devices can be calculated by using the $\Im$ operator:

$$u_p(z) = \Im(u_1(z),\ u_2(z),\ ...,\ u_n(z)),$$

where $\Xi = \sum_{i=1}^{n} \Xi_i$.

One can see that the $\Im$ operator is simply a product of the individual u-functions. Thus, the device Universal Moment Generating Function UMGF is: $u_p(z) = \prod_{j=1}^{J_m} u_j(z)$. Given the individual UMGF of devices defined in equation (11), we have: $u_p(z) = \prod_{j=1}^{J_m} (1 - A_j + A_j z^{\Xi_i})$.

Series devices: When the devices are connected in series, the device with the least performance becomes the bottleneck of the system [17] [18]. This device therefore defines the total system productivity. To calculate the u-function for system containing n devices connected in series, the operator δ should be used: $u_s(z) = \delta(u_1(z),\ u_2(z),\ ...,\ u_m(z))$, where $\Xi = \min\{\Xi_1,\ \Xi_2,\ ...,\ \Xi_m\}$ so that

$$\delta(u_1(z),\ u_2(z)) = \delta\left(\sum_{i=1}^{n} P_i z^{a_i},\ \sum_{j=1}^{m} Q_j z^{b_j}\right)$$

$$= \sum_{i=1}^{n} \sum_{j=1}^{m} P_i Q_j z^{\min\{a_i,\ b_j\}}$$

Applying composition operators $\Im$ and δ consecutively, one can obtain the UMGF of the entire series-parallel system. To do this we must first determine the individual UMGF of each device.

Devices with total failures: Let consider the usual case where only total failures are considered and each subsystem of type i and version v_i has nominal performance Ξ_{iv} and availability A_{iv}. In this case, we have: $Proba(\Xi = \Xi_{iv}) = A_{iv}$ and $Proba(\Xi = 0) = 1 - A_{iv}$. The UMGF of such a device has only two terms can be defined as in equation (11) by

$$u^*_i(z) = (1 - A_{iv})z^0 + A_{iv}z^{\Xi_{iv}} = 1 - A_{iv} + A_{iv}z^{\Xi_{iv}} \quad .$$ Using the $\Im$ operator, we can obtain the UMGF of the i-th system device containing k_i parallel devices

$$u_i(z) = \left(u^*_i(z)\right)^{k_i} = \left(A_{iv}z^{\Xi_{iv}} + (1 - A_{iv})\right)^{k_i} \quad (12)$$

The UMGF of the entire system containing n devices connected in series is:

$$u_s(z) = \delta \begin{pmatrix} \left(A_{1v} z^{\Xi_{1v}} + (1 - A_{1v}) \right)^{k_1}, \\ \left(A_{2v} z^{\Xi_{2v}} + (1 - A_{2v}) \right)^{k_2}, \ldots, \\ \left(A_{nv} z^{\Xi_{nv}} + (1 - A_{nv}) \right)^{k_n} \end{pmatrix} \qquad (13)$$

To evaluate the probability $Proba(\Xi \geq W)$ for the entire system, the operator Φ is applied to equation (13):

$$Proba(\Xi \geq W) = \Phi(u_s(z) z^{-W}) \qquad (14)$$

V. THE CAT SWARM OPTIMIZATION METHOD

One of the more recent metaheuristic approach based on swarm intelligence optimization is the Cat Swarm Optimization (CSO) algorithm (a branch of algorithms designed through inspiration from nature). The new optimization algorithm in the field of swarm intelligence was developed based on the common behavior of natural cats. It has been found that cats spend most of their time resting and observing their environment rather that running after things as this leads to excessive use of energy resources. They always remain alert and move very slowly. When the presence of a prey is sensed, they chase it very quickly spending large amount of energy. Inspired by these behavioral patterns, Chu and Tsai proposed a new optimization algorithm called Cat swarm optimization (CSO) [19].

A. Seeking mode

This sub model is used to model the cat during a period of resting but being alert-looking around its environment, thinking and deciding about next move. Seeking mode according to Chu et al. [20] is described below.

Step 1: Make j copies of the present position of cat k, where j = SMP. If the value of SPC is true, let j = (SMP − 1), then retain the present position as one of the candidates.

Step 2: For each copy, according to CDC, randomly plus or minus SRD percent the present values and replace the old ones.

Step 3: Calculate the fitness values (FS) of all candidate points.

Step 4: If all FS are not exactly equal, calculate the selecting probability of each candidate point by equation (1), otherwise set all the selecting probability of each candidate point be 1.

Step 5: Randomly pick the point to move to from the candidate points, and replace the position of cat k.

$$P_i = \frac{\left| FS_i - FS_b \right|}{\left| FS_{max} - FS_{min} \right|}, \text{ where } 0 < i < j$$

FS_b is the best solution so far, FS_{max} is the largest FS in the candidates, and the FS_{min} is the smallest one.

If the goal of the fitness function is to find the minimum solution, let $FS_{max} = FS_b$, otherwise $FS_b = FS_{max}$

Step 6: Randomly pick a newly generated solution to move and replaces the position of cat_k

Figure 2: Seeking mode (sleeping and looking)

B. Tracing mode

The tracing mode can be seen as the exploration mechanism that avoids quick convergence. The tracing mode can be described as follows:

- Update the velocities $V_{k,d}(t)$ for every for every dimension for the cat_k at the current iteration according to Eq. 1.

$$V_{k,d}(t) = V_{k,d}(t-1) + r_1 \times c_1 \times \left[x_{best,d}(t-1) - x_{k,d} \right]$$
$$d = 1, 2, \ldots, M \qquad (15)$$

Where $x_{best,d}(t-1)$ is the position of the cat with the best fitness value at the previous iteration and $x_{k,d}(t-1)$ is the position of cat_k at the previous iteration, c_1 is a constant value and r_1 is a random value between 0 and 1.

- Check if the velocities are in the range of maximum velocity. If the new velocity is over-range, set it to the limit.

- Update the position of cat_k according to Eq. 2.

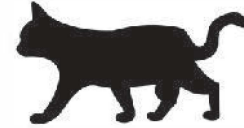$$x_{k,d}(t) = x_{k,d}(t-1) + v_{k,d}(t) \qquad (16)$$

Figure 3: Tracing mode (chasing)

C. The CSO Algorithm

The CSO can represented easily by combining both the seeking and tracing mode and giving a combined set of solution rules [21]. It consists of eight steps:

1- Generate random population.

2- Randomly select a point of reference as a Cat.

3- Generate all possible candidates for a cat.

4- Find the fitness value of the candidates.

5- If the fitness value of a candidate is better, change the position of the cat.

6- Calculate the velocities of each dimension of cat and thus change the resultant position of the cat.

7- Calculate the fitness values of the resultant position

8- If the fitness value of the resultant position got from step (7) is better than that of step (8), change the position of the cat.

The optimum design algorithm developed for power design based on cat swarm method treats the sequence number of the components technology in the list selected for each sub-system components as a design variable [22]. The optimum power design algorithm consists of these following steps; using CSA is sketched basically as shown in Fig. 4
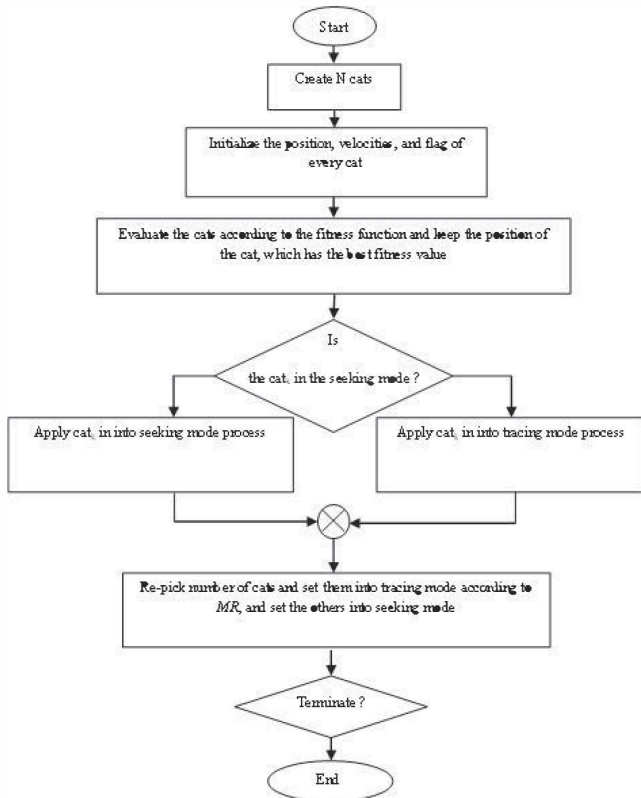

Figure 4: Basic flowchart diagram for CS algorithm

V.   ILLUSTRATIVE EXAMPLE

The hybrid solar gas power plant is located in Hassi R'Mel natural gas field in Algeria. The plant combines a 25 MW through concentrating parabolic solar array in conjunction with 125 MW combined gas turbine plant.
The electrical power station system which supplies the consumers is designed with five basic subsystems as depicted in figure 2. The electrical power system can be described as follows: The electrical power is generated from the solar and gas units (subsystem 1). Then transformed for high voltage (HT) by the HT transformers (subsystem 2) and carried by the HT lines (subsystem 3). A second transformation occurs in

HT/MT transformers (subsystem 4) which supplies the MT load through the MT lines (subsystem 5). Each device of the system is considered as unit with total failures. The characteristics of the products available on the market   for each type of device are presented in table 1. This table shows for each device availability A, nominal performance Ξ and cost per unit C. Table 2 shows the power demand levels and their corresponding durations.
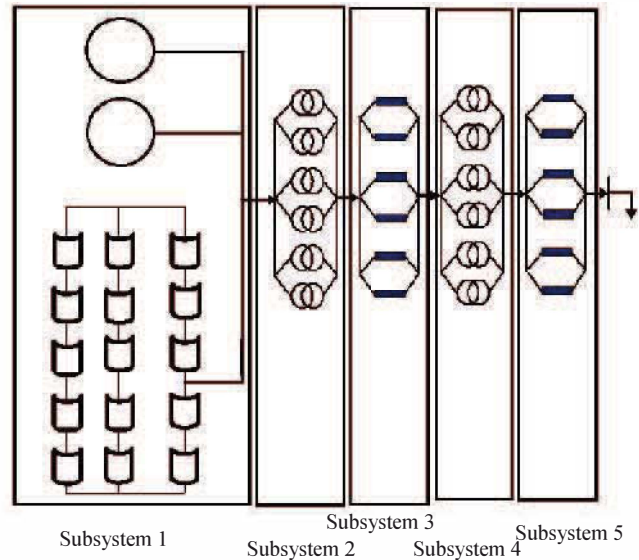

Fig. 4 Détailed electrical power system

TABLE I.   DATA EXAMPLES

Sub-system	Device Number	Availability A	Cost C mln $	Performance (MW)
Power Units	1	0.994	77	65
	2	0.988	64	60
	3	0996	45	25
HT Transfo-rmers	1	0.996	2.805	120
	2	0.992	2.272	100
	3	0.997	2.594	120
	4	0.993	2.569	100
	5	0.997	1.857	100
HT Lines	1	0.975	1.985	150
	2	0.987	1.983	140
	3	0.971	1.842	140
	4	0.986	1.318	130
HT/MT Transfo-rmers	1	0.992	0.842	60
	2	0.982	0.875	80
	3	0.984	0.745	60
	4	0.983	0.654	40
	5	0.957	0.625	30
	6	0.968	0.608	40
	7	0.969	0.492	60
	8	0.979	0.415	30
MT Lines	1	0.988	0.456	30
	2	0.959	0.432	40
	3	0.989	0.364	20
	4	0.981	0.283	20
	5	0.968	0.242	10

TABLE II.   Parameter of Cummulative Curve

Load (MW)	140	125	100	60
Duration (h)	1752	1752	3504	1752

TABLE III.   Optimal Solution for Reliability Optimization Problem

Constraints		Topology	Optimal Topology	Cost, Reliability and Performance		
C_0 mln $	Ξ_0 MW			C mln $	A %	Ξ MW
86	150	Subsystem 1	1-2-3	94.532	0.998	150
		Subsystem 2	1-1-3			
		Subsystem 3	2-2-3			
76	120	Subsystem 1	1-1-2-2-4-5	74.250	0.954	120
		Subsystem 2	1-2-3-3-4			
		Subsystem 3	2-2-3-4			
		Subsystem 4	2-3-4-4-5-5			
		Subsystem 5	1-1-2-2-3			
70	100	Subsystem 1	1-2-2-2-5-5	67.56	0.997	100
		Subsystem 2	2-2-3-3-5			
		Subsystem 3	2-2-3-3-3			
		Subsystem 4	2-2-3-3-4-5-7-7			
		Subsystem 5	2-2-3-3-4			

Conclusion

This paper describes how to implement the metaheuristic algorithm for finding the optimal series- parallel multi state power system configurations.

The algorithm using heuristic information, selects, among a wide range of components available in the market, suitable versions and allocates them to structures in order to achieve maximum system reliability under cost and performance constraints. The efficiency of this algorithm depends on the parameters selection and the update method. A set of values of Cat swarm parameters have been tested. The efficiency of this algorithm depends on the parameters selection and the update method. A set of values of Cat swarm parameters have been tested. The parameters considered are those that affect directly the computation of the formulas used in the algorithm (SMP, SRD, C_1 and MR). We tested several values for each parameter, all the others being constant. The values tested were: The values for these parameters that converge rapidly to optimal solutions were: SMP = 5, SRD = 0.2, C_1=2.05 and MR = 0.7.

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